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TECHNOLOGY REVIEW

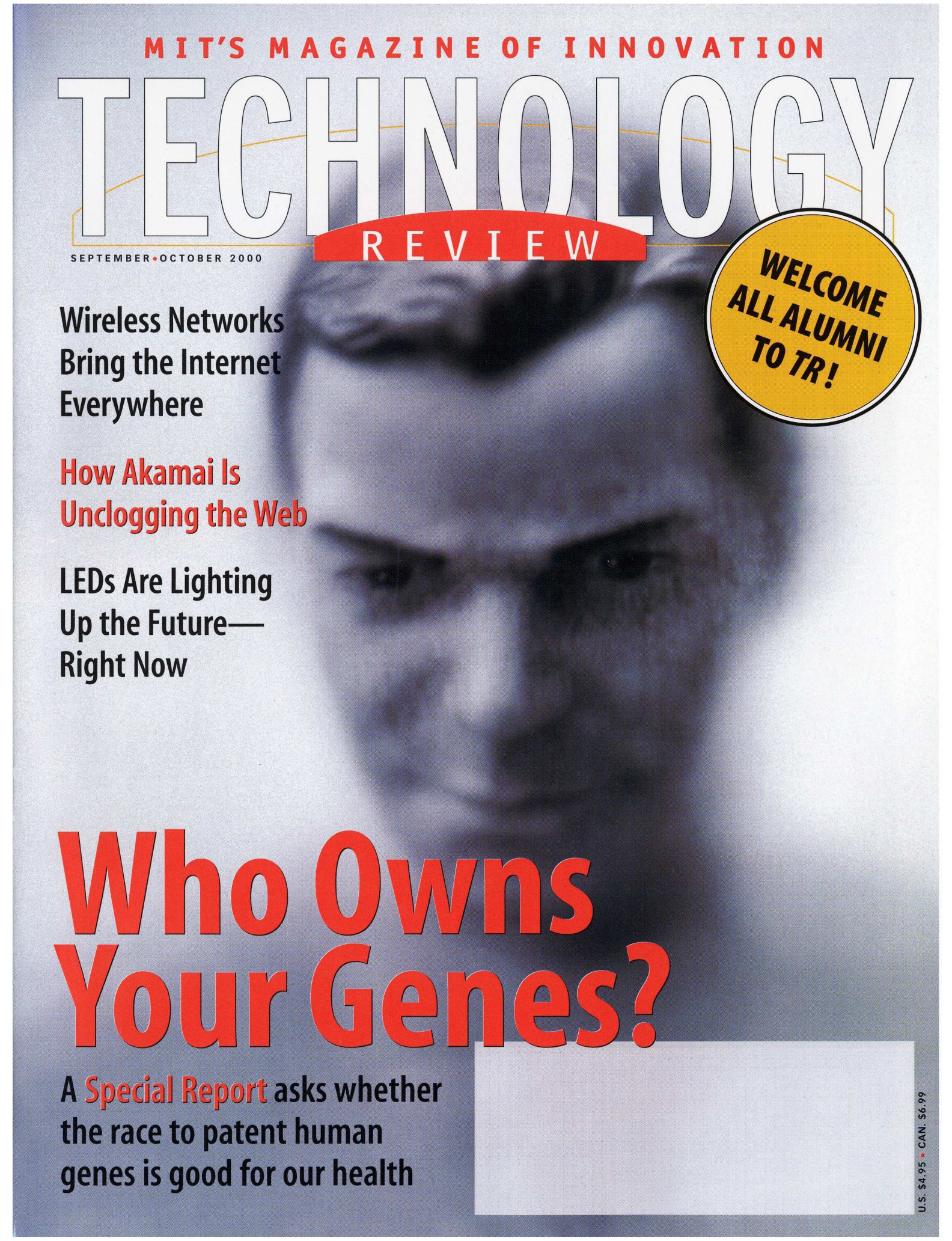
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WELCOME ALL ALUMNI TO *TR*!

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Who Owns Your Genes?

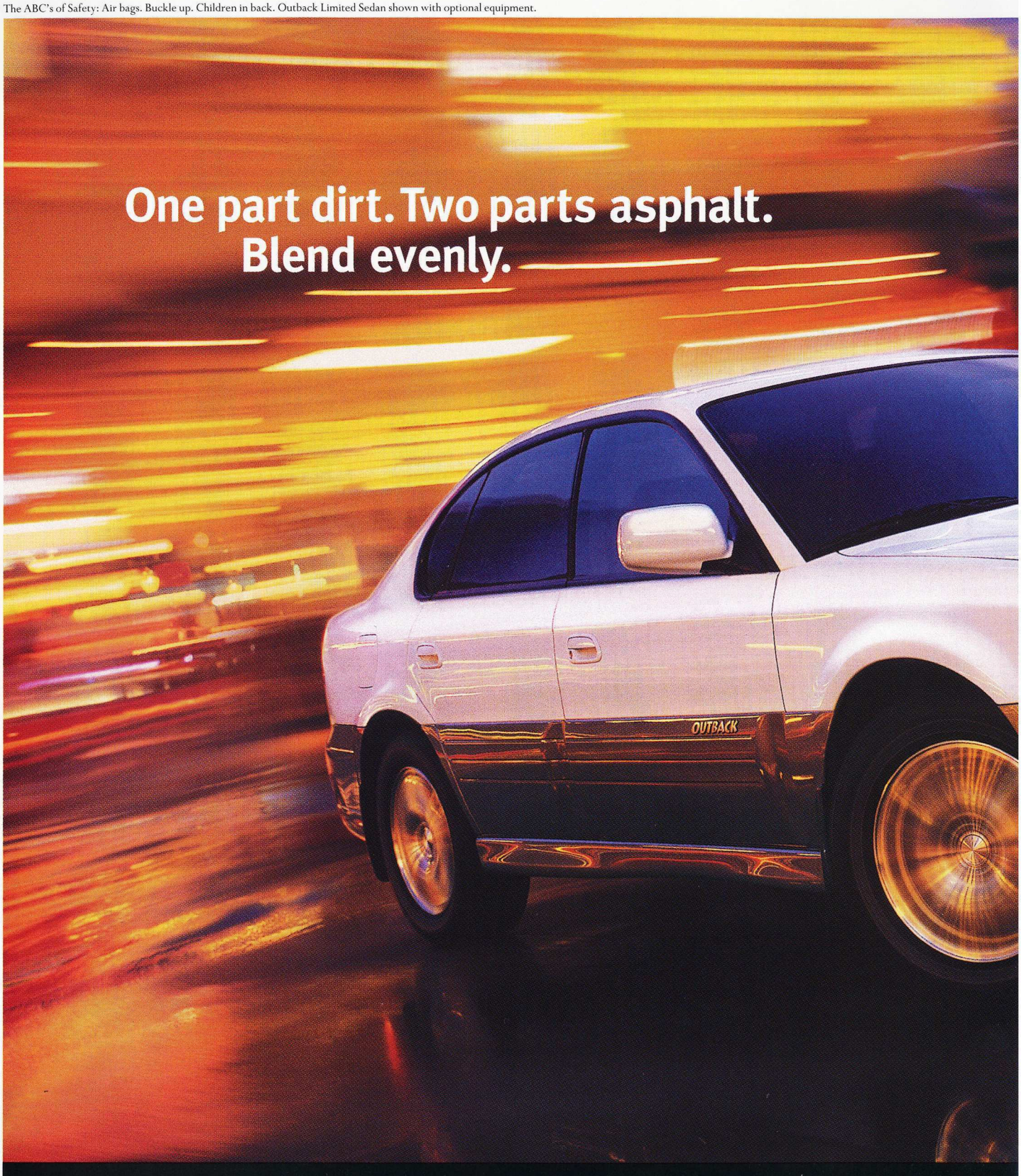
A Special Report asks whether the race to patent human genes is good for our health

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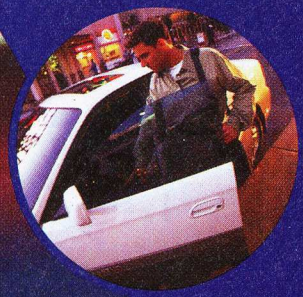
The ABC's of Safety: Air bags. Buckle up. Children in back. Outback Limited Sedan shown with optional equipment.



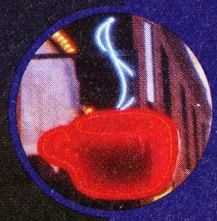
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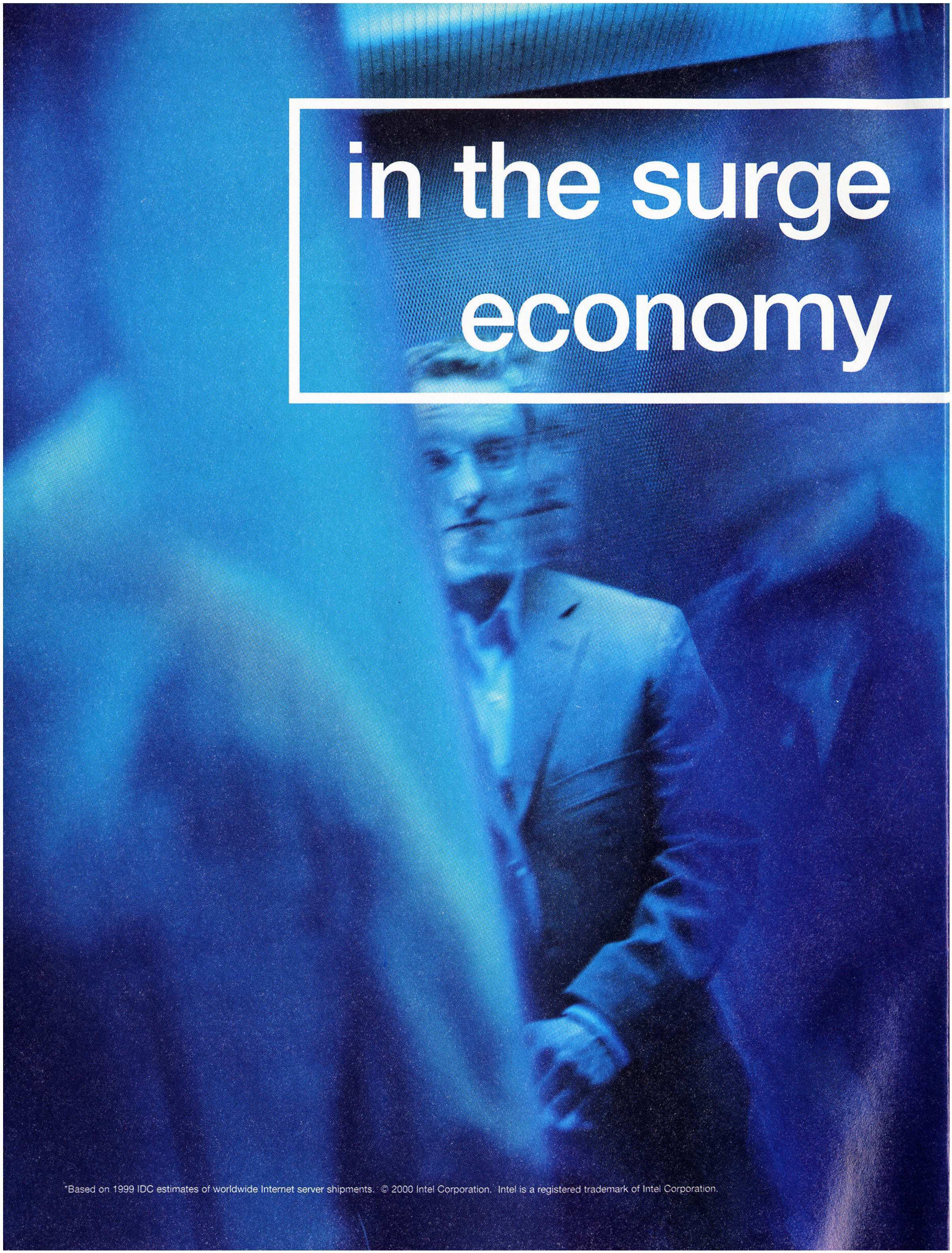




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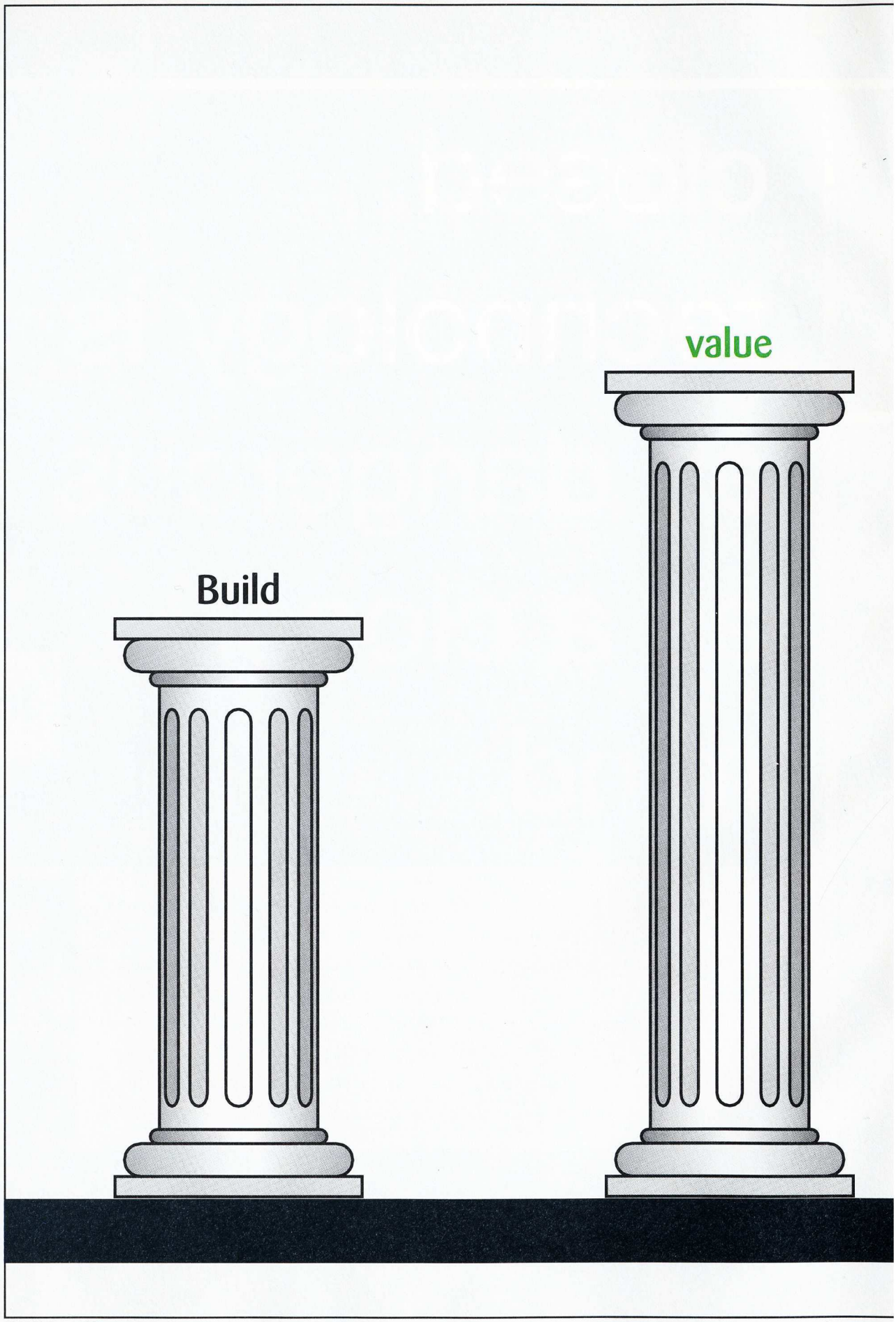
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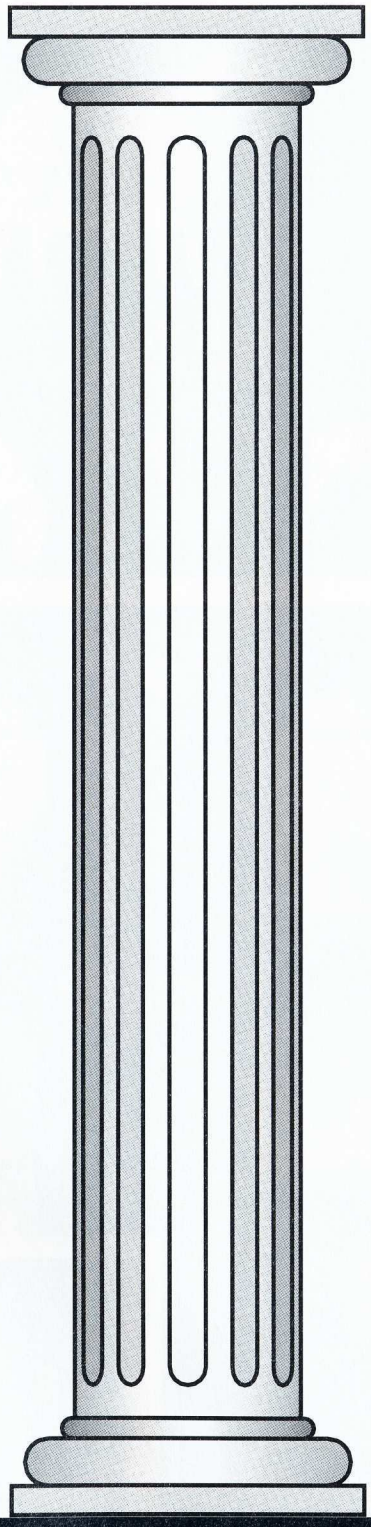
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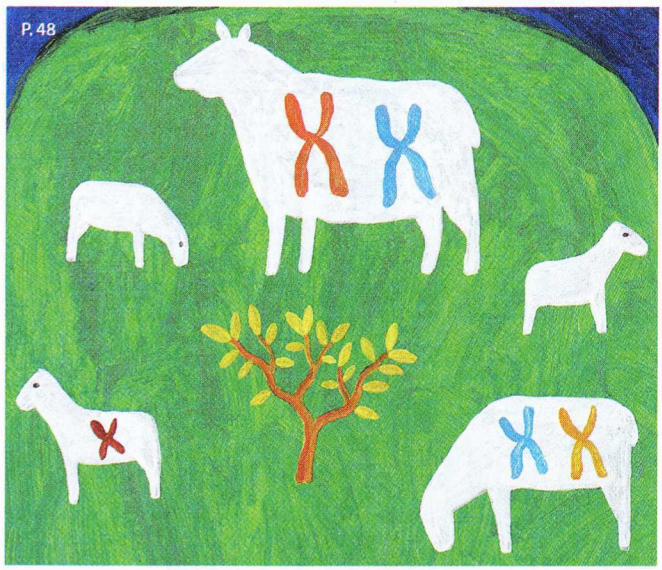
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A farm boy from Utah struggled—and failed—to save his creation from the Bill Gates of his age.

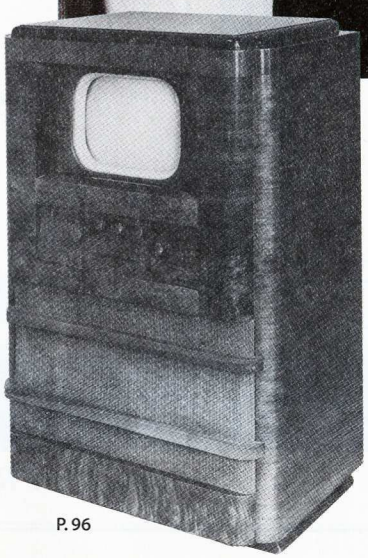
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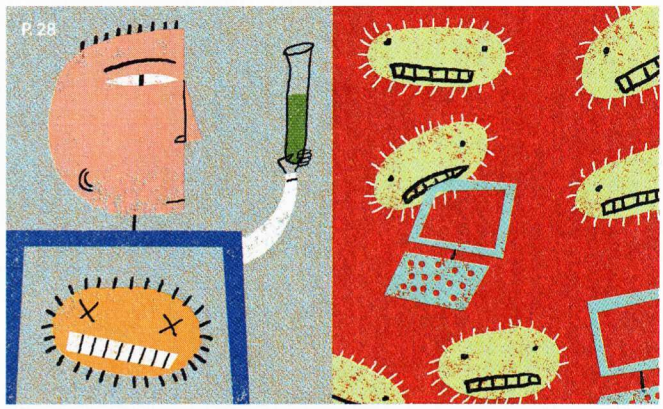
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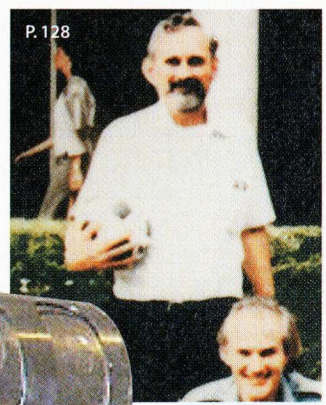
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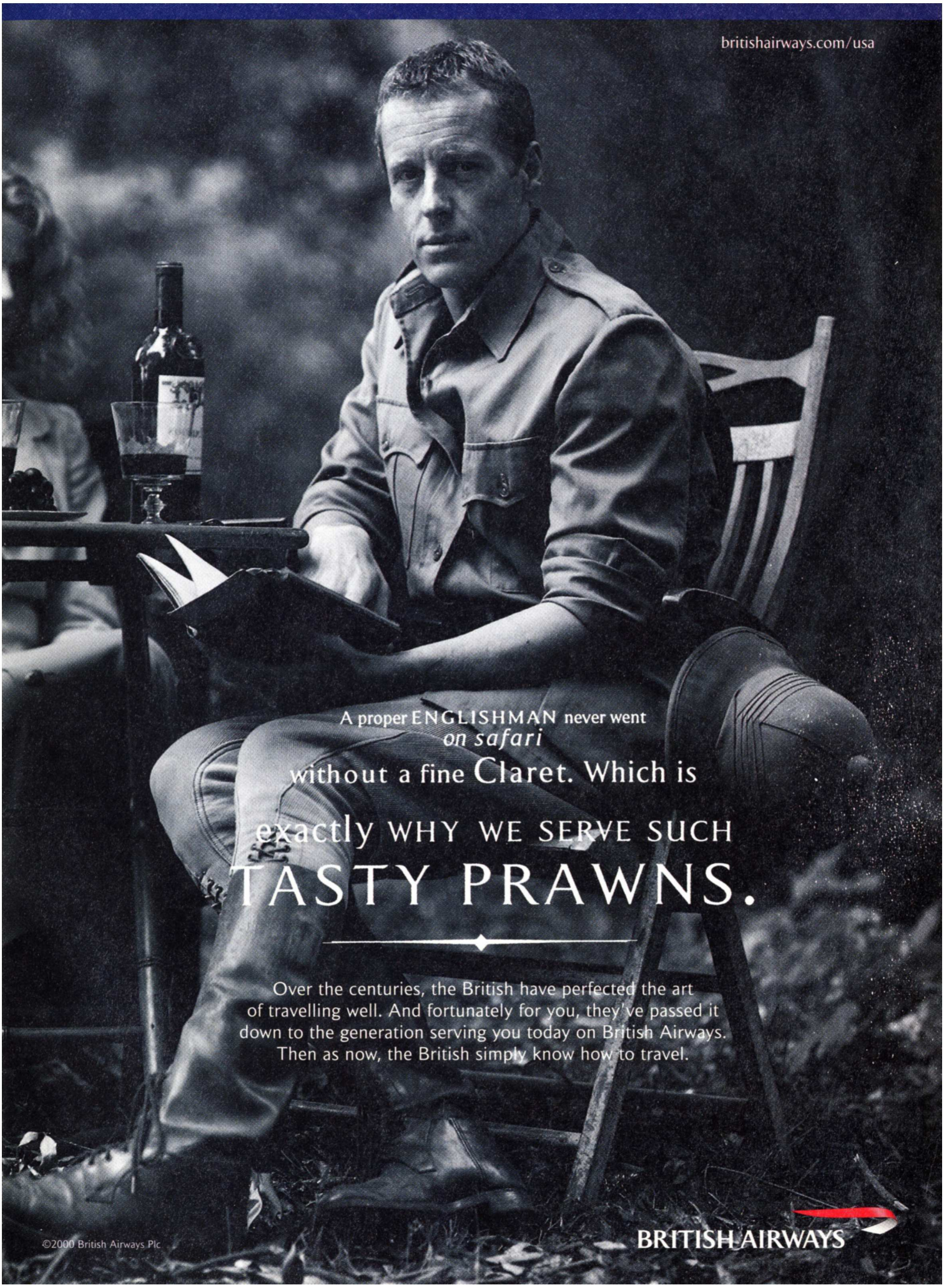
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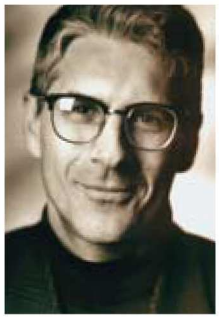
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Gene Genie

FOR ALL THE HULLABALOO SURROUNDING THE COMPLETION OF THE ROUGH DRAFT of the entire human genome, this feat doesn't mean much. The DNA sequences gathered so far are little more than raw material for new therapies and new knowledge of how the body works. As columnist Steve Hall points out *(see "Botstein's Caveat," p. 115),* the real work of refining the raw material has just begun. And in that work, rights to DNA sequences will be critically important.

Yet those rights will become increasingly controversial as time passes, because they intersect with an important and as yet unanswered question: Should it be possible to patent human genes? Biotechnology corporations argue that without the ability to profit from their work, bestowed by patent rights to specific genes, they will have no incentive to invest in R&D. In this issue's cover package on gene patenting, that point of view is lucidly presented by William Haseltine, CEO of Human Genome Sciences—an early and important player in the race to develop genetically based medicines *(see "The Case for Gene Patents," p. 59).*



But the corporate point of view isn't the only one that should be heard in the coming debate over gene patents, argues writer Seth Shulman. In a strongly opinionated proposal, Shulman offers his own prescription *(see "Toward Sharing the Genome," p. 60).* He suggests that the raw genetic sequences should always remain in the public domain, as a zone free of intellectual property claims. Like the national parks, the initial product of the Human Genome Project is a part of our biological heritage that should be preserved and protected for future generations, Shulman argues. It's fine, he says, for patents to be granted on specific treatments developed from genetic data. But the raw DNA sequence itself should remain in the common weal.

Who's right? The corporate chieftain or the crusading penman? We can't presume to make that call for you; the issues are too new and complex. Clearly, the common good and the incentives for corporate R&D both need to be protected. The central issue, as in many important technology controversies, is how to strike the right balance. To provide the factual background to help you decide where you come down on the spectrum connecting private and public goods, we offer an informative survey of gene patenting by *TR*'s own Antonio Regalado. In "The Great Gene Grab," on page 48, Regalado takes you into the history of gene patents (they've been around longer than you might think). His reporting provides the context needed to evaluate the other viewpoints in the package. When you've come to your own conclusions, we invite you to share them with your fellow *TR* readers in an online forum at www.techreview.com/forums.

Wherever you come down on the balance between the private sector and the public weal, we feel confident that, after reading this package, you'll agree on one thing: These issues, which will only grow more significant over the years to come, need to be aired in a full public debate that ranges all the way up to the halls of Congress. They're too important to be left only to appointed officials in the Patent Office who often lack any formal training in science and ethics. They are, after all, our genes, and we ought to help decide who has the right to exploit them.

—John Benditt

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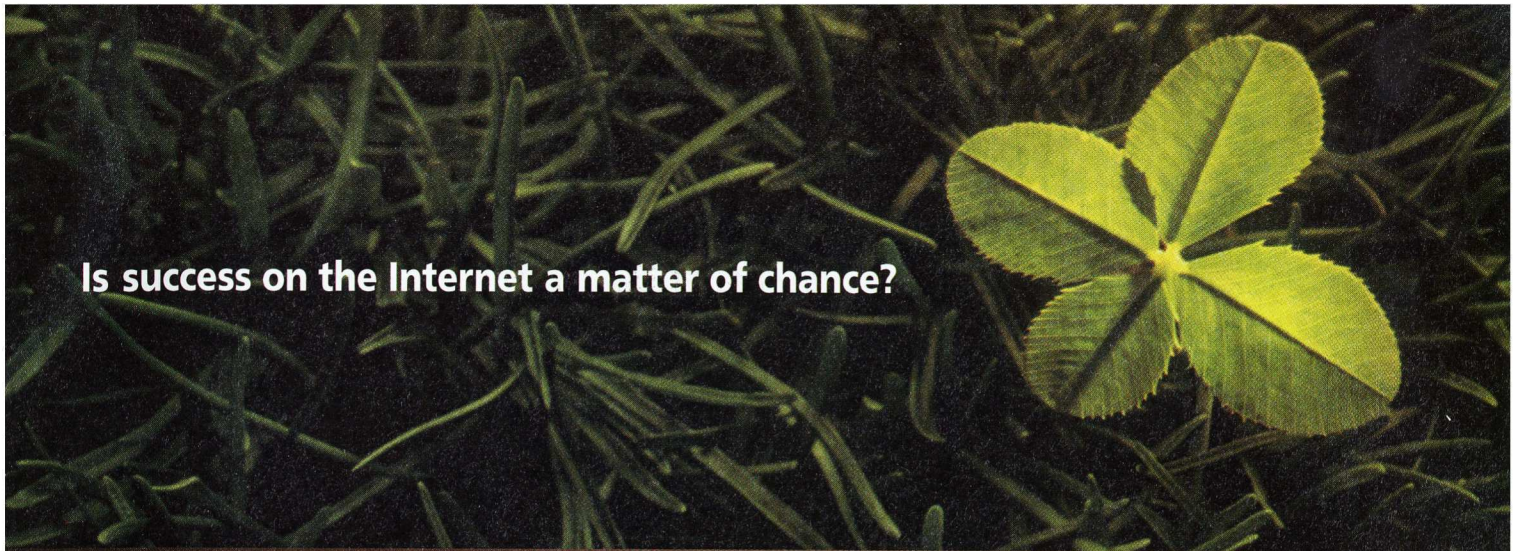
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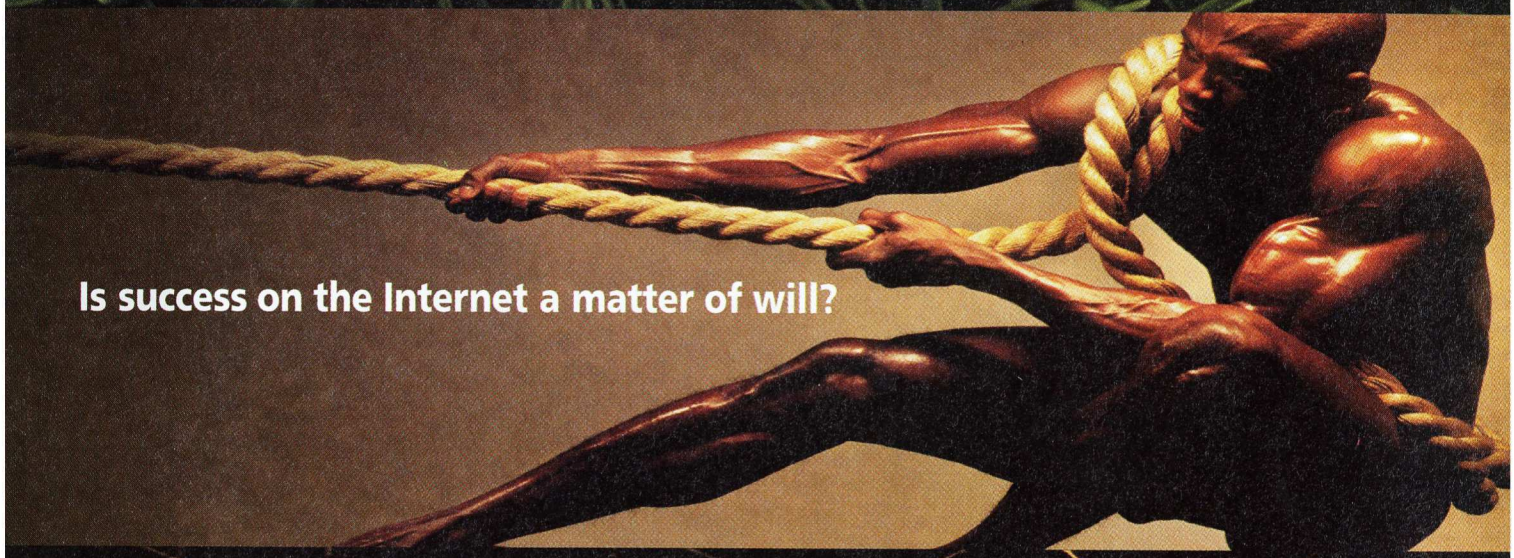
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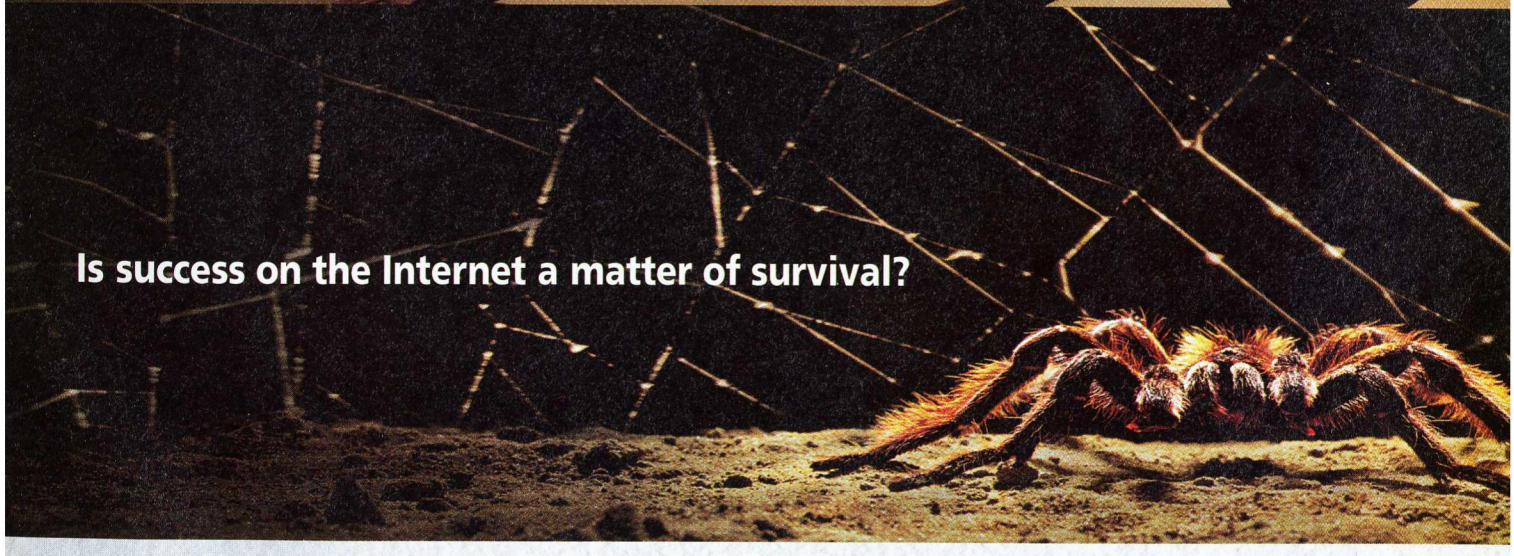
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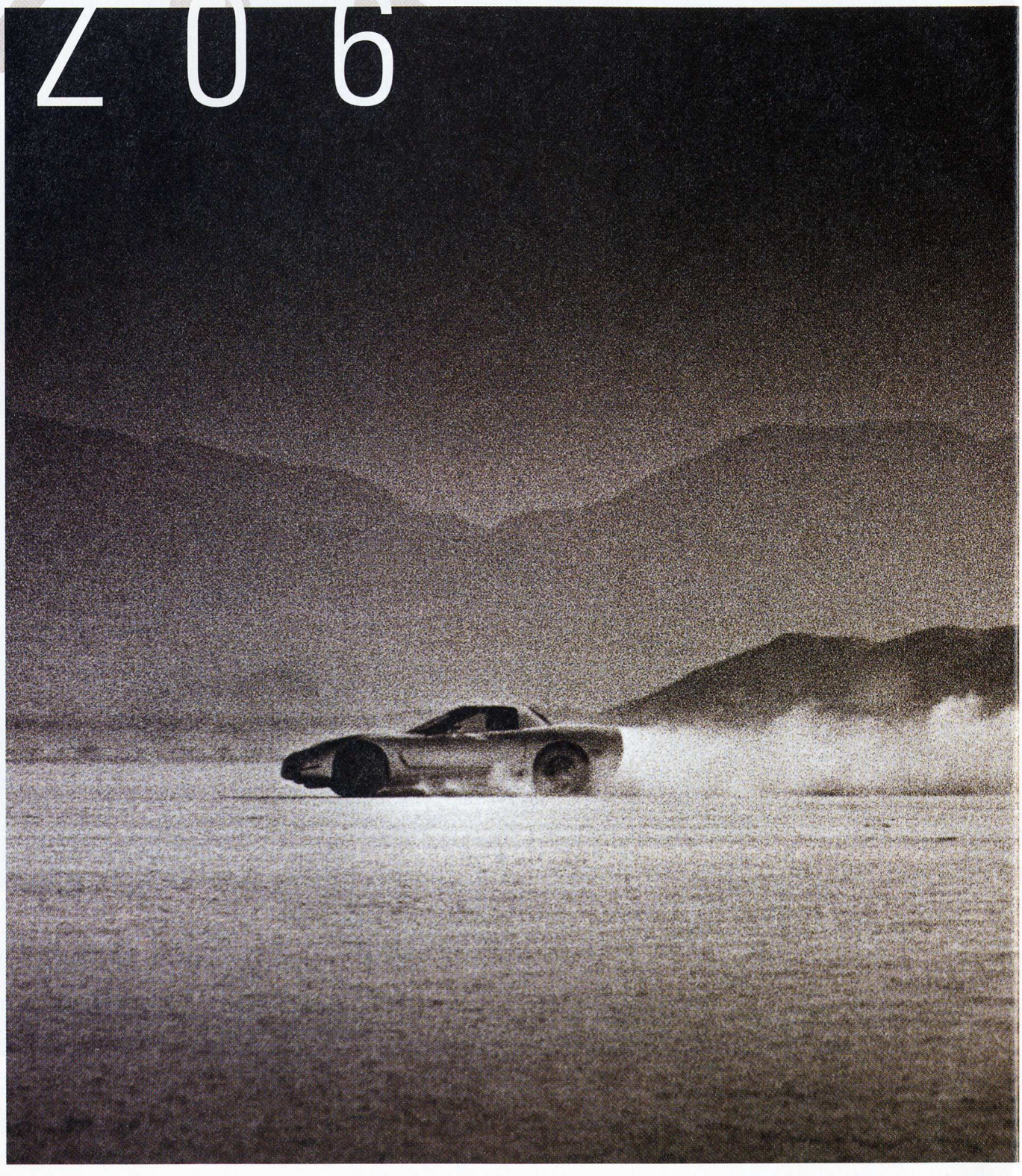
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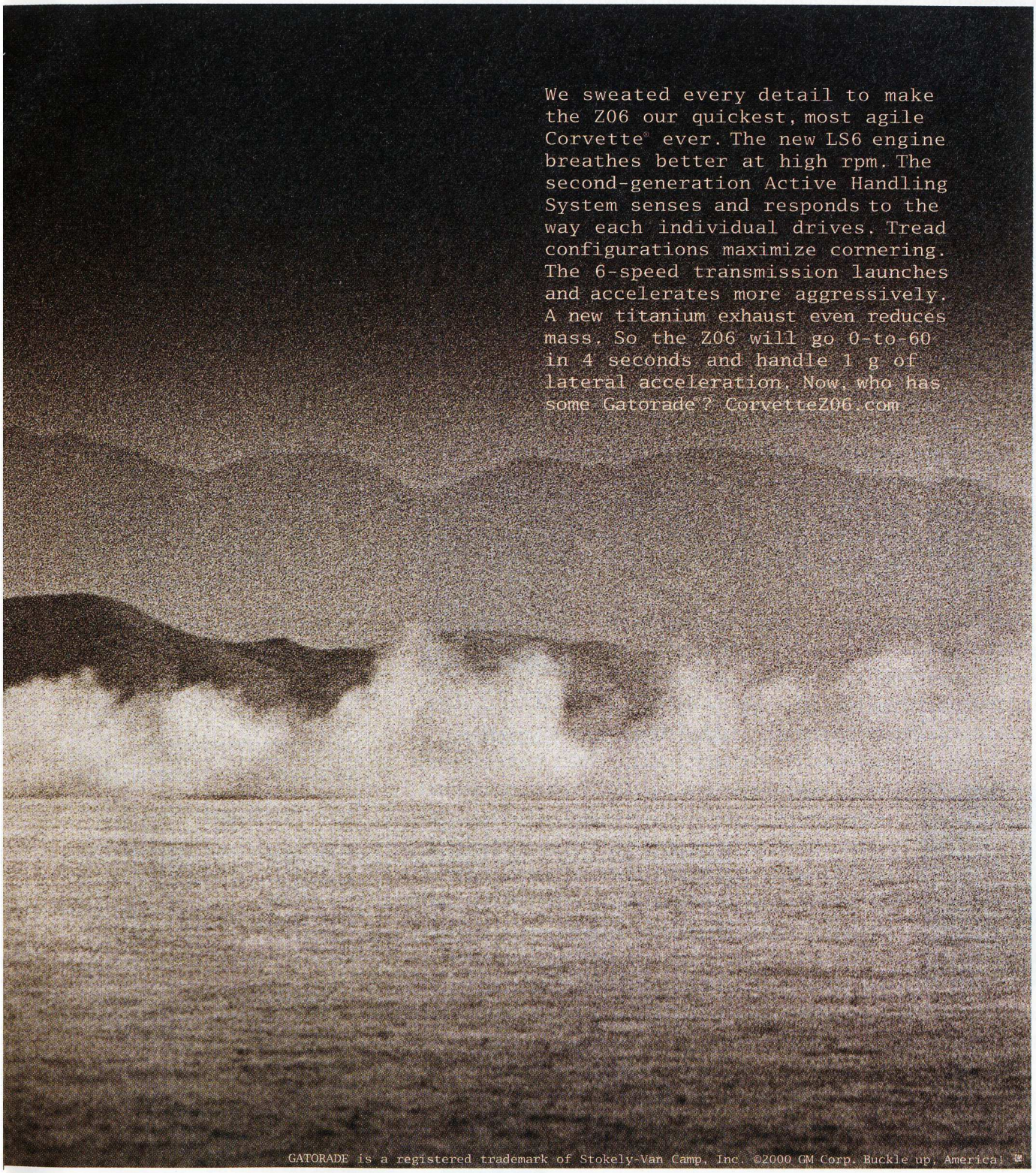
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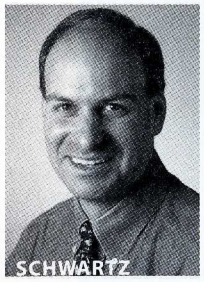
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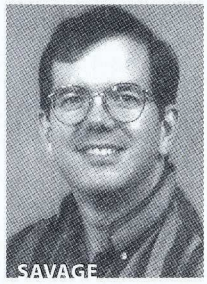
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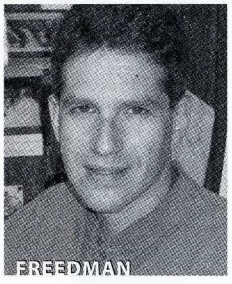
How can we balance the public good with private companies' patent claims on the human genome? In "Toward Sharing the Genome" on p. 60, writer **Seth Shulman** puts on the pundit's hat to suggest some bold answers, including declaring the raw sequence data of the human genome to be an "IP [intellectual property]-free zone." Since the publication of his book *Owning the Future* (Houghton Mifflin, 1999), which examines today's battles to control the genome and other high-tech intellectual property, Shulman has been in demand as an authority on IP. Although fun, this takes him away from his latest book, an early history of the airplane. But even there, he says, he can't escape IP: "The book ends up talking about the nine-year legal battle between the Wright brothers and a competitor."


SCHWARTZ

For lengthy IP battles, though, **Evan I. Schwartz** has Shulman beat. In "Who Really Invented Television?" (p. 96), Schwartz chronicles farm boy Philo Farnsworth's 30-year struggle—and ultimate failure—to keep RCA from usurping his invention, television. When Schwartz visited 92-year-old widow Pem Farnsworth and her son Kent in Fort Wayne, Ind., he got a taste of the human toll that battle took. "The whole story is tragic," says Schwartz. "Here's a guy who invented one of the most important things of the century, and the family hardly has anything." Schwartz, a contributor to *Business 2.0* and *Wired,* found out about Farnsworth while working on his two books, *Webonomics* and *Digital Darwinism* (both from Broadway Books).

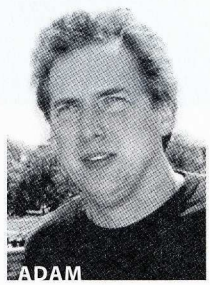

SAVAGE

If **Neil Savage** were a cartoon character, the idea-indicating light bulb over his head would by now have been replaced by a light-emitting diode (LED). The Lowell, Mass.-based freelancer confesses that while writing "LEDs Light the Future" (p. 38), he began to have LEDs on the brain. "I started noticing them everywhere—especially traffic lights." Traffic lights that last a decade are just one application of the new generation of LEDs that could make the 120-year-old light bulb a quaint relic. Savage has written for *Astronomy, The Scientist* and the Discovery Channel.


FREEDMAN

MIT's Media Lab is an enticing environment for a journalist. The gadgets are glitzy and the people quirky—but they know how to handle the press. In reporting "The Media Lab at a Crossroads" on p. 70, **David H. Freedman** had to work a bit to get past the veneer of the slick demos and get folks to open up about the lab's shortcomings as well as its strengths. A senior editor at *Forbes ASAP* and the author of *Corps Business: The 30 Management Principles of the U.S. Marines* (HarperBusiness, 2000), Freedman expects that not everyone will be pleased with his focus on the lab's identity crisis. Still, he prefers it that way: "I get nervous if no one is upset when an article comes out."

What makes Washington, D.C.-based freelancer **John Adam** nervous, on the other hand, is the coming wave of wireless devices that will extend the tendrils of the Internet further into our lives. Although Adam eagerly awaits the possibilities he describes in "Internet Everywhere," starting on p. 86, he has nightmares of voice mail hell, solicitation overdoses and personal tracking devices. "It's a good thing techies tend to have a libertarian bent and try to give power to the individual," he says. Adam's work has appeared in *IEEE Spectrum* and *The New York Times.* TR


ADAM

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TECHNOLOGY REVIEW

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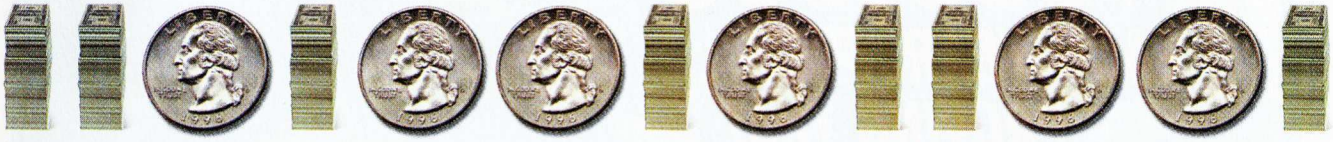
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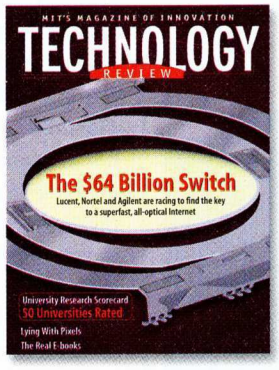


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"Publishers only want to save on printing costs and lock in a path from their hard disk to your wallet."

All About E-books

ALTHOUGH I AGREED WITH MUCH OF Steve Ditlea's excellent article regarding the e-book revolution ("The Real E-books," *TR* July/August 2000), I do think he missed an important element in the growth and acceptance of the e-book industry: print-on-demand publishing. Print-on-demand is fueling the growth in the market, allowing readers to choose their preferred reading platform—even if it's paper. Although print-on-demand looks and feels like traditional printing, the economics are strictly e-book. With a minimal investment in a print-on-demand setup (only an extra formatting step and a discussion with the printer), publishers are able to offer a new work as both an e-book and a print-on-demand paperback to consumers. Although in the future the majority of books may be offered in electronic versions, traditional publishers and e-publishers alike can incorporate print-on-demand technologies to cut costs and soften the blow, as it were, to paper-loving consumers.



ANGELA BENNETT
Internet Book Company
San Francisco, CA

LOCKING UP E-BOOKS IS A POINT THAT Ditlea mentioned only in passing but is central to the topic of e-book publishing on the Internet. Although some e-books can be printed, such as those from Project Gutenberg (for free) and some other sites (for a fee), most commercial e-book offerings in PDF format are encrypted by the publisher and cannot be printed.

These locked-up books will not really be available to lend from libraries, since they are restricted to only one computer or hardware viewer, and they will certainly not be resold in used bookstores. They will essentially evaporate when you need to buy a new computer, and after they are no longer commercially viable, they will simply evaporate from the Internet. Then they will never enter the public domain when the copyright term expires.

Publishers aren't interested in a global free public library—they only want to make more money by saving on printing costs and locking in a path from their hard disk to your wallet and brain, complete with the appropriate demographic information with which to target ads to you (non-taxable, as Ditlea points out). We need to analyze the role of the encryption that the big publishers intend to place on e-books, or we will accept an architecture that will end up destroying our culture based on the (real) book.

ERIC ELDRED
EldritchPress.org
Derry, NH

AN OTHERWISE INTERESTING ARTICLE was marred by Ditlea's total dismissal of dedicated e-readers. The only comment on the value of dedicated readers was made by the CEO of Peanut Press, a company whose products compete with dedicated readers. I have such a device (as well as a Palm Pilot and a desktop computer), and its uses and readability are far superior to "general-purpose hardware."

RAY MONTALVO, JR.
Culver City, CA

THE REASON THAT STEPHEN KING CAN sell e-books online is that he's Stephen King. And Stephen King only got to be that way through very expensive promotional gambits such as movies that made him a recognized brand. So the "cutting out the middleman" argument for e-books is disingenuous. The middleman is making those people want the product in the first place.

Saying that e-books will save literature is like saying MP3s will save music. The instant they figure out how, the middlemen will be back running both domains anyway. And Johnny Unknown will still be at square one: No one will even know his book is there.

STEVEN AUGUSTINE
San Diego, CA

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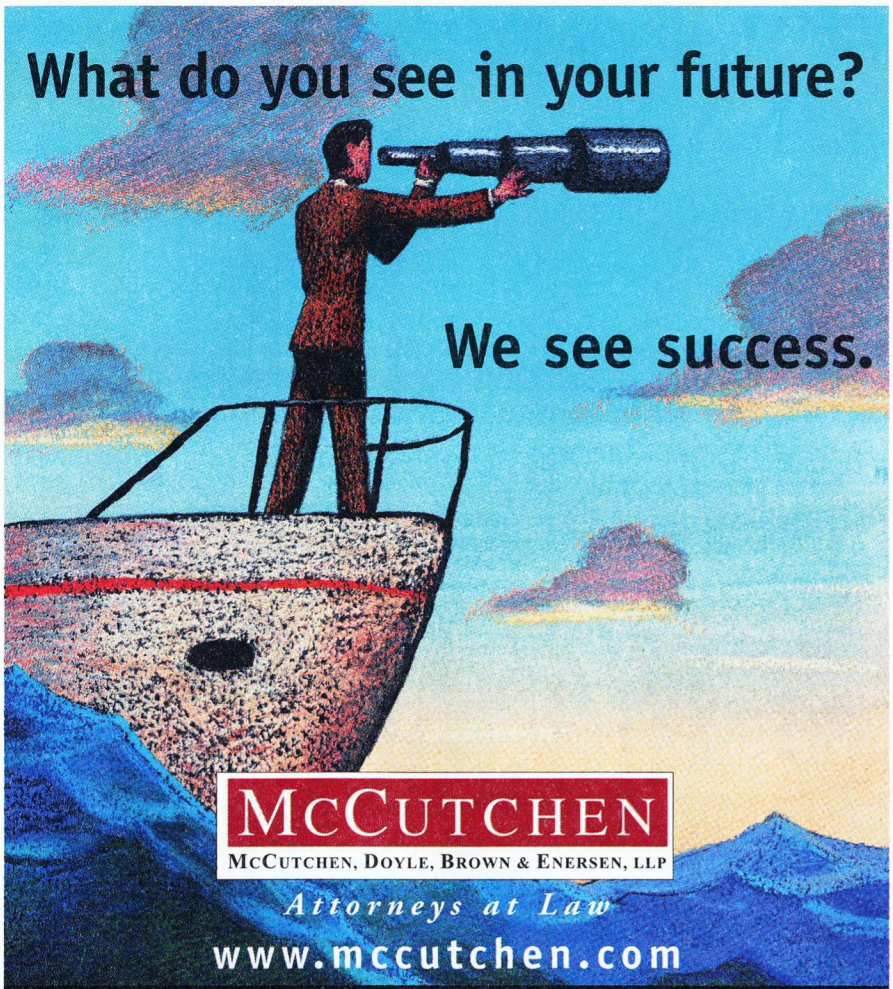
Golden Gift

C. S. PRAKASH IS RIGHT ABOUT THE possible difficulties with the various patents involved in the development of provitamin A-enriched "golden rice" ("Hungry for Biotech," *TR* July/August 2000). We at the Hebrew University of Jerusalem own a patent on one of the genes that was utilized to construct the golden rice. We have decided to offer the gene for free, provided that golden rice itself is not patented and that farmers in developing countries will be able to buy it for no more that what they now pay for regular rice. I challenge other patent holders to follow in our steps.

I realize the benefits of the patenting system and do not object to patenting innovations in biotechnology and using those patents to make money—as we have done ourselves. However, golden rice is an exceptional case: It provides no benefit but to people who suffer from vitamin A deficiency and eat mainly rice. These people are living in very poor regions, and they will never be able to pay for patent licenses. Hopefully, the successful utilization of golden rice will serve as a lever to change public opinion about the benefits of genetically modified plants.

We will, of course, claim our rights on the patent when it is used in other innovations (other crops, different countries, etc.) that will benefit people who can afford to pay for them.

JOSEPH HIRSCHBERG
Head, Department of Genetics
The Hebrew University of Jerusalem
Jerusalem, Israel



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PRAKASH REFERS TO THE "CERTIFIED safety of biotechnology-derived foods." Certified by whom? The Food and Drug Administration seems to have left safety considerations up to biotech companies, who see nothing wrong with snipping genes out of one species and inserting them into a completely unrelated one, thus blurring distinctions between plants and animals. This constitutes a nightmare for people with food allergies or religious or ethical concerns about eating animals. We need to evaluate genetic engineering's products more carefully before turning them loose in the environment and in people's stomachs.

BINA ROBINSON
Director, CIVITAS: Citizens for Planetary Health
Swain, NY

Prakash responds: *Hundreds of studies done in the past 15 years with foods derived from biotechnology have not raised any concern of food safety. Nevertheless, FDA oversight was made mandatory in May for all commercial releases of biotechnology-enhanced foods. And even before then, although such consultation was voluntary, every crop variety approved by the Environmental Protection Agency for sale in the United States was scrutinized by the FDA. Any crop modified with a gene coding for an allergen or altering the nutritional composition of the product must be labeled.*

Fixing Pixels

IN IVAN AMATO'S "LYING WITH PIXELS" (*TR* July/August 2000), George Washington University's Steven Livingston makes the point that video is pixels and pixels can be changed. Well, pixels are data, and data can be secured. Digital watermarking, encryption and physical security technologies could insure an unaltered video data stream from camera to viewer. Perhaps in the future we will treat secure video data just like any other secure data.

BRENT BOLTON
Portland, OR

I DISAGREE WITH JOHN PIKE, WHO IN "Lying With Pixels" said that responsible news organizations would not knowingly participate in deception. In 1994, Cokie Roberts deceptively staged a relatively low-tech "live" report from a TV studio

with only minor repercussions. In my view, most commercial news organizations have the morals of alley cats and are among the least trustworthy of the potential abusers of the available technology.

RICHARD KELLS
Fayetteville, NC

TO ME AMATO'S STORY SAYS THAT IN THE long run people will disbelieve media entirely. When people see enough of the reality-supplanting technology he describes, they will no longer think imagery represents reality—which it never has.

DANIEL J. LYNCH
Partner/Creative Director,
Sp3d Media Design
San Francisco, CA

Babel.com

AT LAST! SOMEONE HAS RECOGNIZED the importance of providing content in more than one language, to empower the reader rather than make him feel inadequate ("Internationalize the Internet!" *TR* July/August 2000). As a multilingual one-stop marketplace for learners of English, we felt it was necessary to provide content in learners' mother tongues as well as English. Developers look at us as if we are mad when we say we want to provide a multilingual, searchable site. Translation may indeed be a costly exercise, but so too is a vacuous site that doesn't answer clients' need for simple understanding.

SAMANTHA DUNHAM
Managing Director, tlcuk.com
London, UK

Lightening Up

THANKS, *TECHNOLOGY REVIEW,* FOR attention to readability, as evidenced by the lighter background tints and larger type in the July/August issue. You also have resisted the urge to place pages and pages of "front" ads before the table of contents. This is one satisfied subscriber.

BOB WALLACE
Sebastopol, CA

Correction *In "Lying With Pixels" (TR July/August 2000), Stanford University computer scientist Christoph Bregler is incorrectly referred to as "Tim Bregler." We regret the error.*

"IT'S A MATCH MADE IN HEAVEN"

— *UPSIDE MAGAZINE, July 2000*

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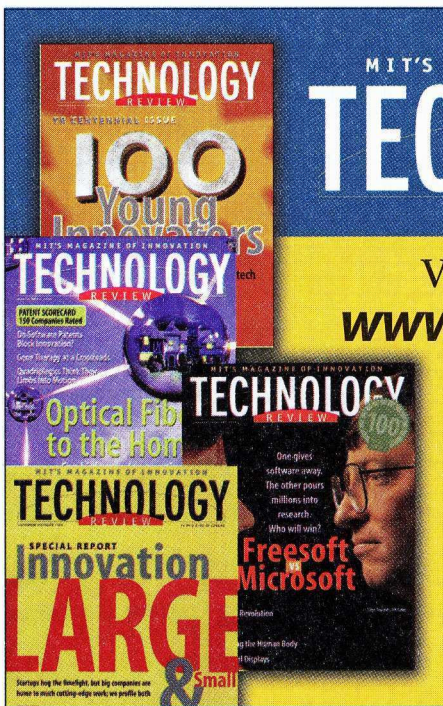
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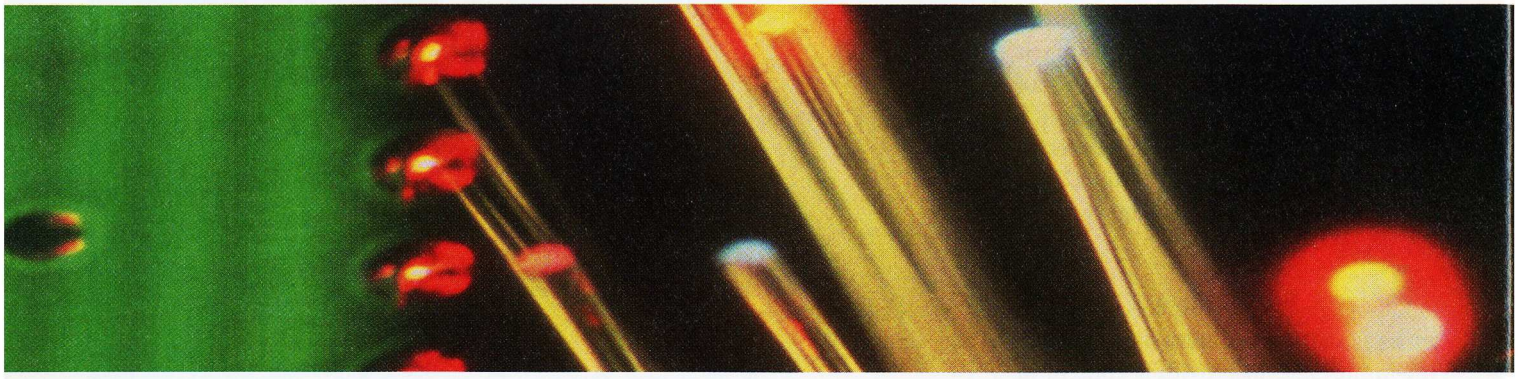
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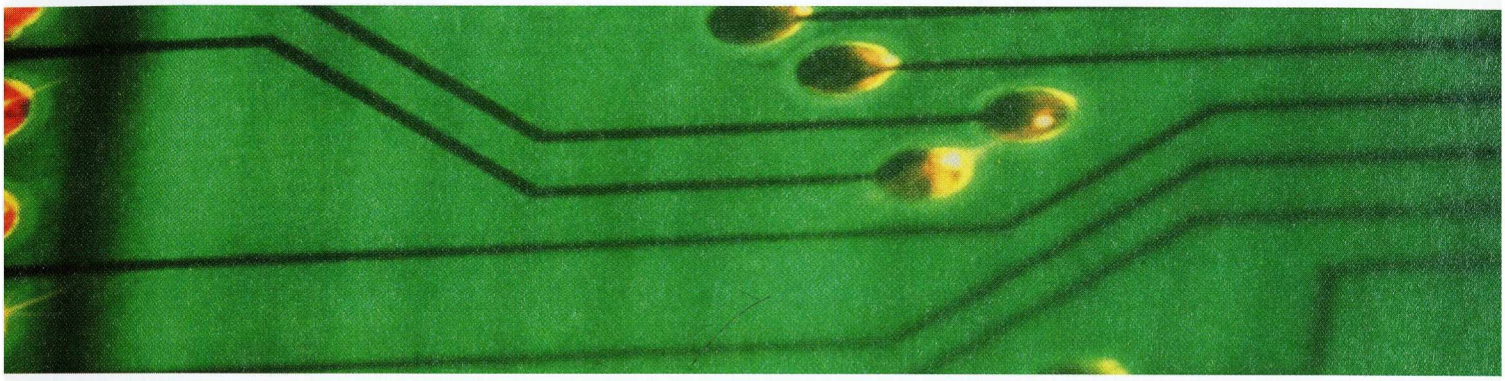
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Cyberagents on Patrol

If Steven Goldsmith of Sandia National Labs in Albuquerque gets his way, one day every computer on the Internet will be part of a massive, cooperative security force. At the heart of the system are intelligent agents—artificial intelligence programs that interact with their environments. The agents watch the network, looking for irregularities such as those produced by intruders gently probing security defenses over a long period of time. Upon detecting abnormal activity, the agents can swing into action by closing data ports, rejecting viruses or cutting a computer commandeered by a malicious insider off from the network.

The strength of the strategy is that it is distributed, requiring no specialized security computers—machines that become favorite targets for attack. In addition, the agents can share information and form a consensus about the nature of an irregularity. The Linux-based system will be ready for use in government and businesses next year, with consumer versions available in three years.



VITO ALUIA

Smart Antenna

Tired of broken cell-phone connections? Help is in sight. Michael Zoltowski, a professor of electrical and computer engineering at Purdue University, combines a pair of antennas with an advanced signal-processing algorithm to create a smart wireless receiver that rejects interference. The two antennas let phones or handheld devices "listen" for the cellular transmitter that is delivering the strongest signal. The receiver then ignores weaker signals while a "space-time equalization" algorithm restores the timing and sequence of codes that cellular base stations use to send data.

The result, Zoltowski says, could be as much as a hundredfold increase in reception accuracy. The technology should also triple the number of users that can occupy a given frequency band—a welcome development as wireless devices proliferate. Texas Instruments, which partially funded the research, is testing a two-antenna phone and hopes to incorporate Zoltowski's algorithm into cellular systems within five years.

Robot Lumberjack



AQUATIC CELLULOSE

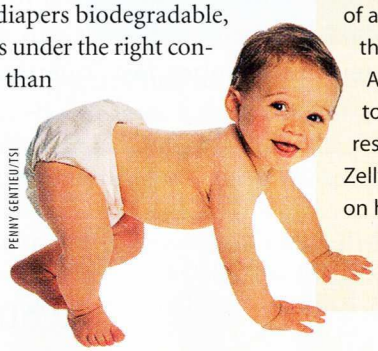
High-tech hardwood harvest.

Furniture built from rainforest hardwoods like teak or mahogany has become a mark of environmental insensitivity. But if lumber companies harvested the perfectly preserved trees left under water by dam construction, they could increase the supply of such woods without endangering tropical habitats. So says Gary Ackles, president of Aquatic Cellulose of Vernon, B.C., who has developed a mechanized "aquatic lumberjack" to recover these valuable commodities far more quickly and safely than human divers could. Aquatic Cellulose is harvesting 1,800 square kilometers of trees from a Brazilian reservoir.

The system consists of a robotic arm controlled from the deck of a barge; the operator maneuvers the arm underwater with guidance from digitally enhanced video and real-time acoustical imaging. The robot arm can cut through a 1-meter diameter tree in 15 seconds and haul logs to the surface from up to 35 meters under.

Fish Diapers

The millions of tons of disposable diapers that Americans throw away every year account for about 1.5 percent of total municipal solid waste. At the same time, the commercial fishing industry catches and throws away more than 20 million tons of unwanted marine wildlife each year. Food scientist Srinivasan Damodaran at the University of Wisconsin may have found a way for one waste problem to help solve another: Put this "sea-kill" to an environmentally friendly use. By attaching water-binding molecules to protein extracts from the discarded fish, he has created a gel that absorbs as much as 600 times its weight in water—making it perfect for disposable diapers. What's more, Damodaran says the protein nature of these gels makes the diapers biodegradable, reducing the burden on landfills. Damodaran says under the right conditions, these new gels would biodegrade in less than 30 days. Protein-based diapers would hold more weight than biodegradable diapers already on the market, which use starch. And since the leftover fish are virtually free, the diapers would be cheap to produce. Damodaran is working on other uses for the gel, including time-release herbicide delivery.



PENNY GENTIEU/TSI

Flowing Documents

Computer-based documents are "changing the way we read," says Polle Zellweger at Xerox's Palo Alto Research Center—and she aims to accelerate that change. In her "fluid documents" project, Web pages, spreadsheets and plain old prose no longer appear as static text and images. Instead, elements of an electronic document smoothly rearrange themselves to make room for more information. A fluid Web page, for example, previews a linked-to site with annotations that push aside text, take residence in the margin, or show up as an overlay. Zellweger points to the tight screen real estate on handheld devices as particularly in need of innovative ways to display complex layers of information.

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All-nighters in the lab.
Caffeine overload in the carrel.



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Last year, Islamshah Amlani of Notre Dame took first place with a transistorless digital logic paradigm that could lead to a new era of super fast "quantum computing."

Merrill Lynch Chairman and CEO David Komansky notes, "Through the Innovation Grants, The Merrill Lynch Forum is challenging the academic research community to take a fresh look at their ideas from a completely different perspective—that of the marketplace."

For entry information, applications, and proof that excellence pays, visit us at **ml.com/innovation**.

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Virtual Diagnosis?

The AIDS virus's ability to quickly mutate and become resistant to new drugs makes it difficult for doctors to choose medications that will work. Researchers at Virco Group in Oxford, England, have created a new tool to give doctors better information about viral drug resistance, allowing them to design effective therapies. Called Virtual Phenotype, the analysis takes the genetic code of a patient's HIV strain and predicts the drugs it will be resistant to. The system, one of the earliest examples of pharmacogenomics in action, reportedly provides the first quantitative analysis of viral drug resistance. The analysis is quicker than actual phenotype testing, which involves growing virus and screening it with drugs, and costs up to three times less. Virco is developing similar databases for cancer and hepatitis B.

Sunburn-O-Meter



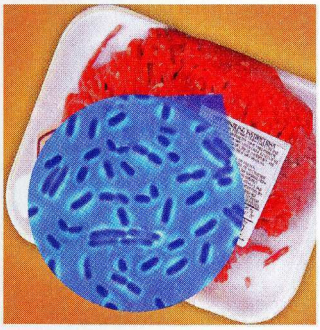
VITO ALUIA

Americans' chances of getting skin cancer are 15 times higher today than 60 years ago. The reason? Increased exposure to ultraviolet radiation (UV) caused by thinning of the ozone layer. A new product may help people beat those odds. Developed by physicist Ori Faran at Technion-Israel Institute of Technology, the Sticker measures the body's accumulated dose of UV, warning its wearer when to get out of the sun.

Photochromic elements in the Sticker change color as they absorb UV. By varying the concentration of these elements, Faran has produced versions for a range of skin types. When the Sticker turns red, apply more sunscreen; if it hits orange, it's time to go home. Skyrad, a startup incubated at Technion, plans to introduce Stickers in the U.S. next spring. Each single-use Sticker will cost 10 to 20 cents.

Fiber Optic Food Safety

Each year, contamination by *E. coli* bacteria causes more than 70,000 cases of food poisoning. Present methods for detecting these germs in food entail making bacterial cultures and take eight to 48 hours to deliver a verdict. A fiber-optic probe originally intended for sniffing out biowarfare agents works in as little as 15 minutes, says microbiologist Daniel DeMarco at the University of South Florida.



VITO ALUIA

The probe consists of an optical fiber whose tip is coated with antibodies that pick up bacteria in the food being tested. Researchers then add fluorescently tagged antibodies to the sample. These labeled antibodies stick to the bacteria on the probe. A laser pulse sent down the probe triggers fluorescent emissions that travel back up the fiber when bacteria are present. The probe, developed by Research International in Woodinville, Wash., and the Naval Research Laboratory, is three to four times more sensitive than other detection systems, DeMarco says. He has tested the instrument on ground beef and apple cider and is adapting it to sense *Listeria* and *Salmonella*, two other common food poisons.

Microwaving Tumors

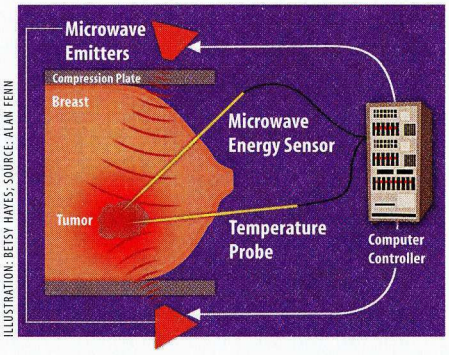


ILLUSTRATION: BETSY HAYES; SOURCE: ALAN FENN

Missile detection technology may provide the future treatment of choice for breast cancer. Alan J. Fenn of MIT's Lincoln Laboratory developed the system as a phased-array radar antenna to foil enemy jamming. Searching for other applications when military funding dried up, Fenn stumbled onto the possibility of using his creation's precisely controlled emissions of microwave energy to treat cancer. Earlier attempts to use microwaves to kill cancer cells failed because of the difficulty in focusing the energy to destroy deep-seated tumors without burning surrounding tissue. Fenn's anti-jamming algorithm precisely shapes the microwave beam to do just that. After giving patients a local anesthetic, doctors insert two needle probes into the tumor to measure temperature and microwave energy levels. They then heat the tumor to about 45 C for 20 minutes. Patients can go home with a couple of Band-Aids.

In early trials, a single microwave treatment shrunk tumors by half within 10 days—a result that requires months of chemotherapy or radiation. Celsion, of Columbia, Md., has licensed the technology and hopes to adapt it to treat tumors in the prostate, lung, liver and pancreas as well.

Boning Up

A new gene therapy technique to grow bone from gum tissue may make life easier for patients who need bone grafts, by eliminating painful removal of bone from a donor's hip. R. Bruce Rutherford and colleagues at the University of Michigan School of Dentistry take a snippet of gum tissue and grow more cells in the lab. They then use recombinant virus to spike the cells with genes for factors that promote bone growth. Next, the researchers seed surgical gel with the treated cells, shape it to fit the area of the graft and implant it. The cells begin producing the growth factors, which prod surrounding bones to grow into the space, and even create new bone themselves. In tests on rats, large areas of bone removed from the animals' skulls grew back in only one month.

Not by Reason Alone

In a recent Wired magazine article, Bill Joy argued that the consequences of research on robotics, genetic engineering and nanotechnology may lead to "knowledge-enabled mass destruction…hugely amplified by the power of self-replication." His medicine: "relinquishment…by limiting our pursuit of certain kinds of knowledge." I don't buy it.

What troubles me with this argument is the arrogant notion that human logic can anticipate the effects of intended or unintended acts, and the more arrogant notion that human reasoning can determine the course of the universe. Let me explain and offer some alternatives.

We are seldom able to assess where we are headed. In 1963, when we built time-shared computers, we did it to spread the cost of a $2 million processor among many users. In 1970, when DARPA pioneered the Arpanet, it did so to avoid buying expensive computers for its contractors, who were told to share their networked machines. Both efforts succeeded, not for these goals, but because they enabled people to share information. The Internet was launched to interconnect networks of computers—no one anticipated that its biggest application would be the Web. Radar was designed for war but ended up as a cornerstone of air transportation. Nuclear weapons research put nuclear medicine on the map. Thousands of innovations all share the same pattern—the early assessment is unrelated to the outcome.

So limited is our ability to assess consequences that it's not even helped by hindsight: On balance, are cars a good or bad thing for society? How about nuclear power, or nuclear medicine? We are unable to judge whether something we invented more than 50 years ago is good or bad for us today. Yet Joy wants us to make these judgments prospectively, to determine which technologies we should forgo!

Developments that today seem fearful may turn into mirages. Take the spiritual machines of Ray Kurzweil that concern Bill Joy. I have a lot of respect for Ray, and I welcome his ideas, as I do Bill's, however outlandish or controversial they may be. But we should draw a clear line between what is imagined and what is likely. To blur this line is tantamount to quackery. Just because chips and machines are getting faster doesn't mean they'll get smarter, let alone lead to self-replication. If you move your arms faster you won't get brighter. Despite fashionable hyperventilation about intelligent agents, today's computer systems are not intelligent in the normal sense of the word. Nor do we see on the research horizon the critical technologies that would lead them there. Should we stop computer science and AI research in the belief that intelligent machines someday will reproduce themselves and surpass us? I say no. We should wait to find out whether the potential dangers are supported by more than our imagination.

Since we can't see where we are headed, should we stop research altogether? This reminds me of a wise old airline employee to whom I was bragging that I had stopped flying with his company because of their lousy safety record. "Listen, sir," he said to me. "If your exit visa from this life is stamped 'death by aircraft,' even if you stay in your bed, the airplane will find you and crash upon you." At this, the dawn of the technology century, it is not fashionable to pay attention to forces outside reason. We should reconsider. All the more so, if we are under the illusion that we understand enough of our universe to successfully regulate its future course, as Joy suggests.

Bill Joy's recent alarm-sounding in Wired missed an important point: Reason by itself cannot guide us in understanding the consequences of new technologies.



We shouldn't forget that what we do as human beings is part of nature. I am not advocating that we do as we please, on the grounds that it is natural, but rather that we hold nature—including our actions—in awe. As we fashion grand strategies to "regulate the ozone problem," or any other complex aspect of our world, we should be respectful of the unpredictable ways nature may react. And we should approach with equal respect the presumption that the natural human urge to probe our universe should be restricted.

I suggest we broaden our perspective to the fullness of our humanity, which besides reason includes feelings and beliefs. Sometimes, as we drive the car of scientific and technological progress, we'll veer because our reason says so. At other times we'll follow our feelings, or we'll be guided by faith. Most of the time, we'll steer with all three of these human forces guiding us in concert, as they have guided human actions for thousands of years. As we do so, we should stay vigilant, ready to stop, when danger is imminent, using our full humanity to make that determination. If we do so, our turning point will be very different from where it may seem today, based on early rational assessments…that have failed us so often. Let us have faith in ourselves, our fellow human beings and our universe. And let's keep in mind that our car is not the only moving thing out there. ◊

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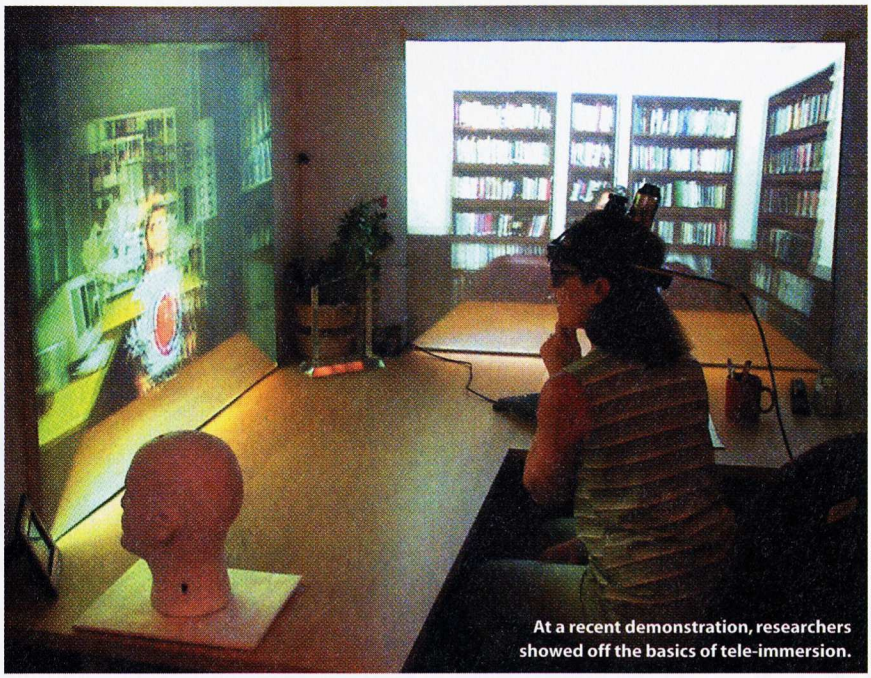
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At a recent demonstration, researchers showed off the basics of tele-immersion.

COURTESY OF JARON LANIER

INTERNET

Meeting the Future

Tele-immersion makes virtual conferencing more real

VIDEO TELECONFERENCING IS OFTEN touted for its potential to promote better communications and curb expensive travel. Yet technology for such virtual face-to-face meetings has yet to catch on as a routine business tool. Among its perceived failings: the inability of participants to make eye contact (due to camera placement limitations), the need for a dedicated "dry room" away from office or lab floors, and a lack of shared workspace for collaborative brainstorming.

Given the expected development of far greater bandwidth than is available with current data lines, what is the next step toward more realistic virtual meetings? The answer is known as tele-immersion, a conceptual hybrid of virtual reality and Star Trek's Holodeck. One of the principal applications areas for Internet2 (a research project involving 170 academic institutions and 50 corporations to develop tomorrow's faster Internet), tele-immersion visually replicates, in real time and in three dimensions, slabs of space surrounding remote participants in a cybermeeting. The result is a shared, simulated environment that makes it appear as if everyone is in the same room.

In May, researchers at the University of North Carolina (UNC) at Chapel Hill, the University of Pennsylvania in Philadelphia, and Advanced Network and Services in Armonk, N.Y., demonstrated for the first time the building blocks of this meeting room of the future. A participant sees two projected "windows" of life-sized colleagues, each hundreds of miles away from the site and each other. Lean forward and the foreground figure and background bookshelf in a window shift slightly in three dimensions, as if right there.

The 3-D view and precise position tracking, however, come at a cost; awkward goggles and a silvery head tracker perched on a user's head are required. Less evident is an array of seven standard video cameras and two special ones that capture distance information by reading light patterns subliminally projected into each participant's environment.

In addition to the need for bulky and costly equipment, the demo suffers from video glitches (just like videoconferencing). Still, it provides a glimpse of what lies beyond today's videoconferencing. And it provides vindication for the more than two years of research by a collaboration of computer scientists from UNC, Penn, Brown University, Columbia University, the University of Southern California, Carnegie Mellon University and the University of Illinois. "It's a significant accomplishment," says Jaron Lanier, chief scientist for the project. "We demonstrated viewpoint-independent real-time scene sensing and reconstruction. And we got rid of the 'dry room.'"

By the end of the decade, when next-generation broadband is in place, immersive conferencing could be rigged from any office or lab. Still, there are challenges. The researchers want to better integrate the real and virtual worlds and provide overlapping workspaces for shared whiteboards and 3-D modeling. In the demo, the edges of the virtual cubicles do not conjoin; ultimately tele-immersion is meant to be seamless. Lanier, who helped invent and popularize virtual reality in the 1980s and 1990s, says the scientists are also working on autostereo screens (for 3-D without glasses) and advances in haptics (for full-hand tactile simulations).

Once tomorrow's Internet is in place, virtual face-to-face meetings through tele-immersion could be possible from any office or lab.

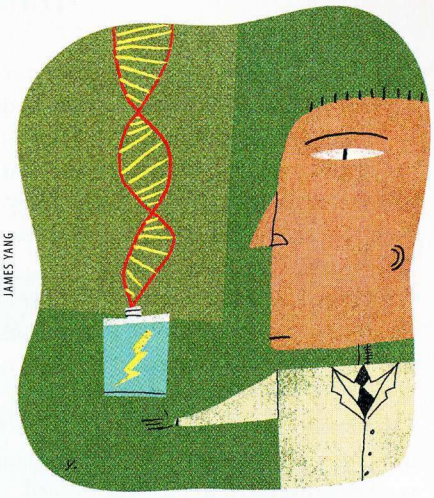
If it all works, you'll finally be able to really reach out and touch someone.

—Steve Ditlea

NANOTECHNOLOGY

Live Wires

Conducting DNA could mean improved biosensors


JAMES YANG

In many ways, DNA is almost the perfect building block for constructing tiny objects on the scale of nanometers (billionths of a meter). In some of the most promising research, scientists have recently learned to synthesize strands of DNA that conduct electricity. These "DNA wires" are made by plating the DNA with a thin coating of metal atoms. However, because the DNA serves only as a scaffold and is completely covered by metal, these wires do not retain all of the valuable properties of DNA, particularly its ability to bind selectively to other molecules. Now, researchers from the University of Saskatchewan have stumbled upon a discovery that could get around this shortcoming and greatly expand the use of DNA in a new generation of biosensors and semiconducting wires.

Researchers in the lab of biochemistry professor Jeremy Lee were investigating methods for stabilizing a novel form of DNA when they came upon a surprising result. They found that at high pH, or very basic conditions, DNA readily incorporates zinc, nickel and cobalt ions into the center of its helix. They knew this was the first step in making DNA conduct electricity. But unlike previous DNA wires, this new type of molecule, which they dubbed M-DNA, not only conducts but does so without losing its inherent ability to bind to other molecules.

The researchers are currently exploring applications that take advantage of M-DNA's properties. One possibility lies in screening for genetic abnormalities. As with other DNA probes, the biosensor would work by binding a specially prepared sequence of DNA with the genetic sample to be tested. But in this case, the fully bound DNA strand is highly conductive; any deletions or mutations in the hybridized DNA act as a barrier that prevents electron flow. A computer can therefore spot these anomalies simply by measuring changes in conductivity.

The biosensor could also be used to identify compounds, such as environmental toxins, drugs or proteins, which bind to the M-DNA. "If we bind something to DNA, metal atoms are kicked out and interrupt the flow of electrons," says Heinz-Bernhard Kraatz, University of Saskatchewan assistant professor of chemistry and a collaborator on the project. Because the reduction in signal strength is proportional to the concentration of the contaminant, the amount of environmental toxin can be readily determined. M-DNA could also be used to screen for new anti-tumor drugs that work by binding to DNA. "Biosensors are only the beginning," says Kraatz. He notes that M-DNA could potentially be used in tiny semiconducting circuits in which the "wires" will be the M-DNA molecules.

University Medical Discoveries, Inc., a Toronto-based technology development company, is providing funding for the project over the next two years. UMDI investment analyst Nick Glover anticipates the technology will be initially used to make a more sensitive DNA chip for genetic testing. "There are other DNA probes, but this one is potentially far more sensitive than other detection systems, and it's also cheap and reusable," says Glover. "The value of an enabling technology in this sector is likely to be significant." **—Linda Wang**

EDUCATION

Physicists as Entrepreneurs

Many parents confront their college-age kids with the question, "What are you going to do with a degree in *that*?" If a few visionaries at Case Western Reserve University in Cleveland succeed, physics majors can say, "Run a company."

That's the goal of the Physics Entrepreneurship master's program just being launched in the Case physics department. "We want to empower physicists as entrepreneurs," says Cyrus Taylor, program director and physics professor. The heart of the program is a thesis in which students focus on a new physics innovation as either the basis of a startup or the solution to a problem posed by a corporate partner. Similar programs exist for engineering and e-business entrepreneurs, Taylor says, but there is nothing like it in physics.

An encounter between physics chair Lawrence Krauss and businessman Robert Stieglitz three years ago led to a lecture series on physics entrepreneurship. Feedback from speakers, students and physics alumni persuaded Krauss and Taylor to turn it into a formal program to provide training that many physics alumni said they were forced to get in "the school of hard knocks."

The first class will begin the two-year program this fall. "My bet is not only that we'll succeed dramatically… but I think that it will become successful enough that it will become a prototype [for similar programs]," Krauss says. **—Erika Jonietz**

PHOTOVOLTAICS

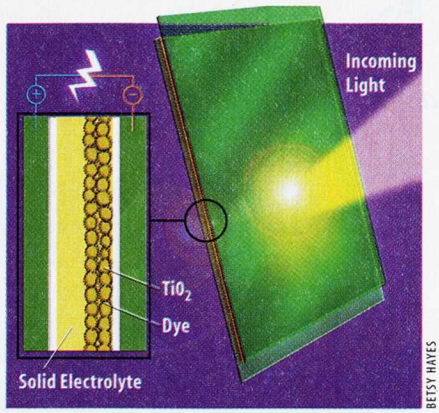
Something New Under the Sun?

Transparent solar cells could find killer app in consumer goods

IMAGINE A SMART CREDIT CARD THAT not only stores electronic money and records your transactions but also has its own energy source. Or a sun roof that delivers electricity to your car battery. Imagine each powered by flexible, ultrathin, see-through solar panels.

These scenarios may not be far off, thanks to a photovoltaic cell production process unveiled by Toshiba scientists in May at the 16th European Photovoltaic Solar Energy Conference and Exhibition in Glasgow, Scotland. The Toshiba design is an improvement to the Graetzel cell, a new type of solar panel that relies on titanium dioxide nanocrystals coated with a dye. When struck by light, the dye "injects" energized electrons into the semiconducting titanium, which generates electrical power. Graetzel cells' advantages over conventional silicon solar panels include transparency, low materials costs and the ability to operate efficiently under cloudy skies.

Earlier Graetzel designs, however, mostly relied on a liquid electrolyte to replenish the dye with electrons; this proved impractical because of the risk of leakage. Toshiba is the first to succeed in encapsulating liquid electrolyte in a durable solid—a "cross-linked" gel that can withstand temperatures of up to 120 C.



BETSY HAYES

Toshiba's solid electrolyte simplifies solar cells.

Shuzi Hayase, chief research scientist at Toshiba's Power Supply Materials & Devices Laboratory in Kawasaki, says the cells achieve a respectable 7.3 percent solar-energy conversion efficiency and should be easy to manufacture. "We do not need expensive production lines and sophisticated vacuum systems currently employed in the manufacture of silicon-based cells. The new cells could be manufactured by [silk-screen] printing technologies."

According to Michael Graetzel at the Swiss Federal Institute of Technology, who invented the basic cell design in the early 1990s, the Toshiba development is "a very important step forward" towards simplifying dye-based cell production. During the next decade, he says, the technology should find its first uses in low-power applications such as sun-powered timepieces (watch manufacturer Swatch already has a prototype) and price scanners. At least seven companies in Japan, Europe and Australia are also developing improved Graetzel cells that may ultimately grace cellular phones, laptop computers and windows in energy-efficient homes.

—Mark Dwortzan

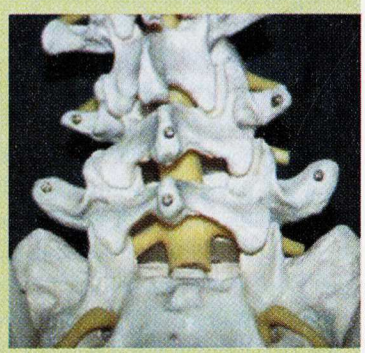
MEDICINE

Spinal Navigation

Accuracy is critical to all surgeries, particularly those involving the nervous system, where the slightest error can cause permanent damage. While neurosurgeons operating on the brain have dramatically improved surgical accuracy over the last several years, similar advances in surgeries involving the spinal cord have proven more vexing. One reason is that while surgeons can navigate inside the skull using an external reference—a head ring fixed to the cranium—it's far more difficult for them to find their way about when doing spinal operations. As a result, there is a significantly high misplacement rate associated with the fixing of screws in the spine—a common procedure to correct deformities and fractures.

To improve that statistic, neurosurgeons at the Jena College of Medicine in Jena, Germany, have developed the first spinal navigation technique that employs CT scans obtained during the surgery. Such real-time imaging has been used for cranial navigation, and the German physicians successfully applied the strategy to spinal surgery by using a mobile CT scanner and small titanium screws implanted in the vertebrae as markers. By touching each of these titanium screws with a pointing device, the surgeon can achieve perfect registration, which means the CT image on display is perfectly aligned with the region being operated upon.

All the instruments used in the surgery are fitted with light-emitting diodes, and the procedure is recorded by an infrared camera. A tracking device fixed on the spine keeps account of the movements made by the patient during surgery—just the breathing can disturb the registration—and allows the navigation system to update its images five to 10 times every second. "The surgeon gets an almost real-time picture of the region of interest, along with the position of all the instruments," says Kristian Ebmeier, a member of the team that developed the system.



MEDICA MUNDI

Small titanium markers help make spinal surgeries more accurate.

The technique isn't necessary for all types of spinal surgeries, says Iain H. Kalfas, head of spinal surgery at The Cleveland Clinic Foundation. However, Kalfas expects the advance will "be helpful" to fix fractures or address tumors and deformities.

—Yudhijit Bhattacharjee



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BIOTECHNOLOGY

A Genetic Rx for Rejection

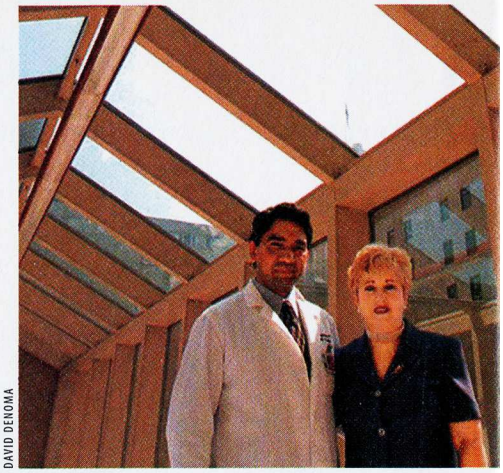
Gene screens determine transplant treatment

ORGAN TRANSPLANT PATIENTS FACE A catch-22. The powerful drugs that suppress their immune systems and protect their new organs from rejection can cause life-threatening side effects, including high blood pressure, susceptibility to infection and even cancer. Now researchers at the University of Pittsburgh Medical Center have found a link between a patient's genes and the chances of rejection that could free many patients from lifelong dependence on immunosuppressant drugs.

Physicians have long known that certain people are more prone to deadly rejection episodes than others, regardless of how well a donor organ is "matched" to their bodies. Studying children who received new hearts, a team led by immunologist Adriana Zeevi has now shown that immune molecules called cytokines are a likely culprit. Cytokines kick the immune system into high gear, revving it up to eliminate foreign invaders—helpful if the intruder is a virus, bad if it's a desperately needed kidney or liver. Zeevi showed that patients whose bodies produce more of a cytokine called TNF-alpha, but less of the cytokine IL-10, were most likely to reject their new organs.

Zeevi's team has developed a simple genetic test to determine a patient's cytokine levels and hopes to forecast which patients can tolerate lower drug doses. "If their findings hold up, then they could say ahead of time, 'You're going to have a liver transplant and you have this genetic profile, so I'm going to both give you lower immunosuppression and try to wean you from the drugs altogether,'" says Julia Greenstein, chief scientific officer at BioTransplant, a Charlestown, Mass., company that specializes in transplantation technology.

To prove the theory, every transplant recipient at Pittsburgh Medical Center is now given the test—almost



DAVID DENOMA

Physicians Mazariegos (left) and Zeevi are using genetic testing to determine drug doses.

500 patients a year. And George Mazariegos, a transplant surgeon who is working with Zeevi, says that by year's end he will begin using the genetic screen to select liver transplant patients who are good candidates for weaning from drug treatment. Initial evidence indicates that as many as 30 percent could qualify. Zeevi and Mazariegos predict that profiling transplant patients' cytokine genes will become standard medical practice in about five years.

—Erika Jonietz

SOFTWARE

Automated Virus Busters

The latest computer viruses—which can e-mail themselves to everyone in a host computer's electronic address book and change their appearance or even rewrite their own code to avoid detection—have created new problems for antivirus companies. But it turns out the most difficult challenge isn't analyzing the viruses or creating fixes for them—it's handling the flood of requests for help during an epidemic. When a fast-spreading virus infects many computers in a very short time, the number of virus samples submitted to an antivirus company for analysis increases by as much as three orders of magnitude, as does the number of requests for the antidote. This kind of jump makes most Web sites crash, but crashing during a virus outbreak is, obviously, a disaster for an antivirus company.



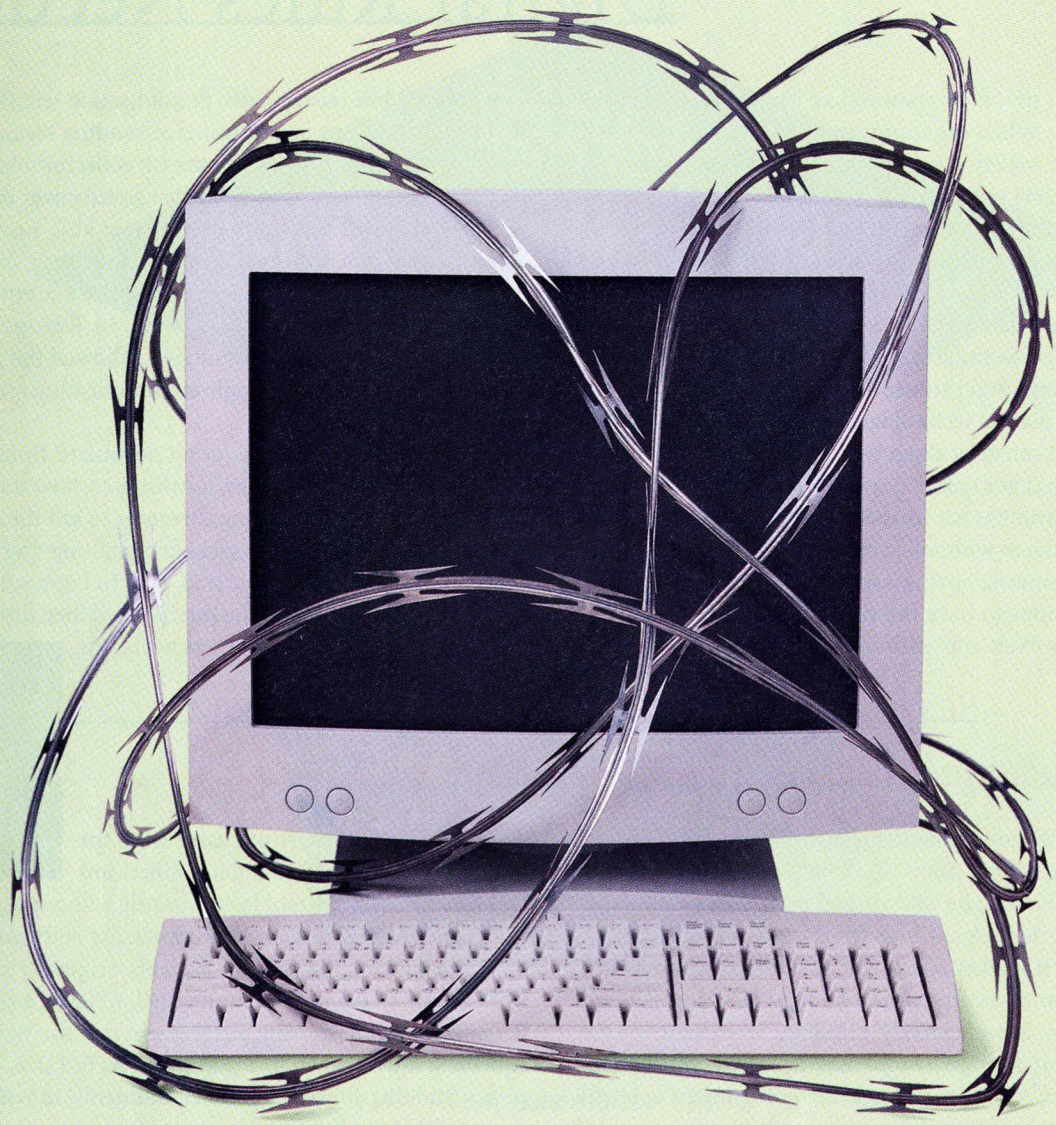
JAMES YANG

Researchers at IBM Research in Yorktown Heights, N.Y., in collaboration with Symantec, makers of the popular software Norton AntiVirus, have engineered ways to weather future outbreaks of even faster-spreading viruses. The first advance is a completely automated virus analysis center that develops antidotes and packages the cures for customers considerably faster than human virus analyzers. In March 1999, it took Symantec's human virus busters six hours to crank out a cure for the Melissa virus, but IBM's system can do it in 40 minutes. Norton AntiVirus users will have access to the automated virus analysis center this fall.

All the speed in the world won't help, however, if a system is overwhelmed. To protect the virus analyzer, the group devised a network of gateways that was surprisingly hard to realize, says IBM antivirus researcher David Chess. "The stuff you would think would be the rocket science wasn't the hardest part," Chess says. "We had to do some unprecedented things to make the gateways robust to communication errors and sudden loads."

Like secretaries opening their boss's mail, the gateways perform triage on incoming viruses. First the gateway finds out if the incoming sample matches previously analyzed files; if it does, the gateway can immediately send the antidote to whoever submitted the virus. If the file matches one that the virus analysis center is working on, the gateway can acknowledge receipt of the virus and later send the antidote when it becomes available. Several IBM patents on the gateway system are pending.

—Deborah Kreuze



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Digital Rules Needed

WHEN IS IT TIME TO SAY "NO" TO INNOVATION? When are innovations so destabilizing that society must intervene? To raise this question isn't to launch down the path toward Luddism. The idea that innovators work under limits isn't new. The great military innovations of World War II spawned legal and practical prohibitions on what could be done with nuclear and biochemical weapons. Medical and pharmaceutical technologies are routinely regulated. So are cars, planes and other transport innovations.

Yet information technologies are often presumed to be in a different category altogether. And there are good reasons to think that's true. Consider two examples. Britain's Labour government has introduced legislation that would make it a crime to withhold a computer password from the country's domestic spying agency. The government also wants its snoops to have the right to read any e-mail and monitor any Web site without even asking for a court order.

Regulation sends a message to digital innovators: Rules still apply, even in their corner of the world.

The U.S. government, meanwhile, limits the quality of cryptographic products—software that encodes secret messages—that can be sold abroad by U.S. companies.

Such barriers are ultimately exposed as folly. Britain's security law, if it takes effect, will soon drive talented people and businesses from the country. U.S. controls on cryptography are effectively rendered irrelevant by the willingness of foreign companies to create and spread "hard crypto," codes too tough for government spies to crack quickly.

The result is that regulators rarely succeed in harnessing IT innovation. But does this mean limits on IT are never desirable? No. Governments can and should draw lines, even in a field as dynamic as information technology. In certain cases the public has the right, indeed the duty, to declare some fields off-limits for further "improvements" because these innovations are just too costly. Innovators can keep on innovating in private if they wish, but the fruits of their labors aren't fit for public consumption.

This sounds draconian, but consider the policy of exempting e-retail sales from taxation. Many innovators applaud this example of enlightened restraint by lawmakers. Taxes on sales via the Web would stifle innovation by discouraging customers and adding to the already high burdens on those building e-businesses.

But innovators shouldn't count on a permanent tax holiday. The policy is discriminatory. It gives a benefit to e-businesses that bricks-and-mortar retailers lack. Someday, and probably someday soon, sales taxes will be imposed on e-retailers. While raising costs, this obligation will stimulate further innovations as e-commerce vendors scramble for ways to more efficiently satisfy the tax collector's demands.

The taxation example shows that government demands on the IT world are neither unreasonable nor insurmountable in practice. Such demands, moreover, can actually quicken innovation because they create a common target for innovators. Think of how, in Europe, rapid innovations in wireless technologies followed the imposition by government of a single communications standard on industry.

Even when regulations don't stimulate innovation, they are justifiable. Consider, for instance, how unbridled innovation in digital copying threatens to kill the proverbial golden goose of IT. Advances in digital copying are creating tools that make it fast and easy to copy songs and movies, downloaded from the Internet and then distributed by e-mail. First came MP3, software for downloading music free of charge from the Internet. An estimated 13 million Americans have already used the tool to copy music without paying for it. Recently, a new version of compression software, MP4, has been making the rounds. Hackers originally stripped MP4 from Microsoft's Windows Media Player, a program designed to handle moving pictures sent over the Web. It can squeeze a movie down to 1 percent of its full size, making piracy and distribution far easier. Suddenly, movie piracy seems within reach of nearly everyone.



This situation can't be tolerated for long. Tools such as MP3 and MP4 should be banned. Music and movies are only the tip of the iceberg. This isn't a matter of protecting rich, highly concentrated industries. If pirated music and movies can be peddled with impunity, what's next? Personal financial data and e-mails? Whole libraries? Photographic collections?

Banning MP3 and MP4 won't be popular. It won't be easy, either. Innovators often argue that any restriction will be mocked, ignored and ultimately discarded. They are often right. The history of nuclear weapons, writ large, proves that. Any ban on a software tool will spawn illegal traffic in that tool. And any ban will require revision.

But drawing a line isn't futile. It creates a useful target for innovators, at least those who recognize that the purpose of technology is to serve people and that societies don't remake themselves merely to satisfy a technological imperative. Drawing a line also sends a broader message to innovators: Rules still apply to their corner of life. ◊

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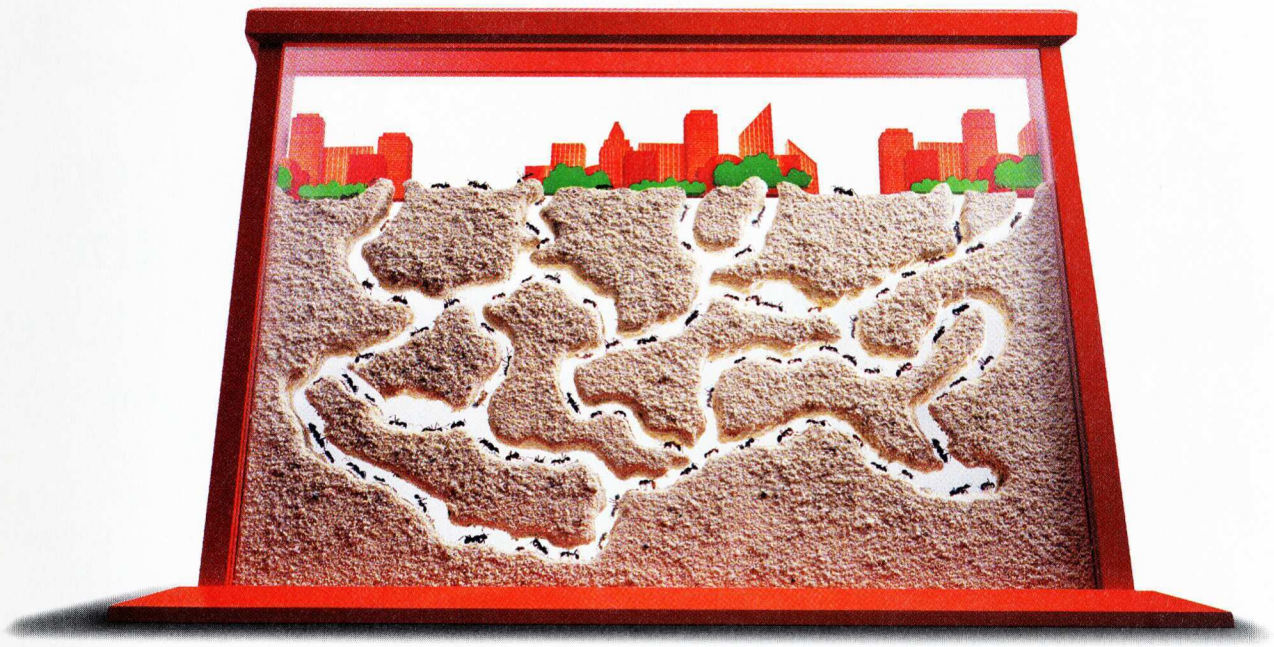
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Roll over, Tom Edison. Drawing on new semiconductor technology, muscular offshoots of those dainty colored dots could shine bright white light that illuminates the world.

LEDs Light the Future

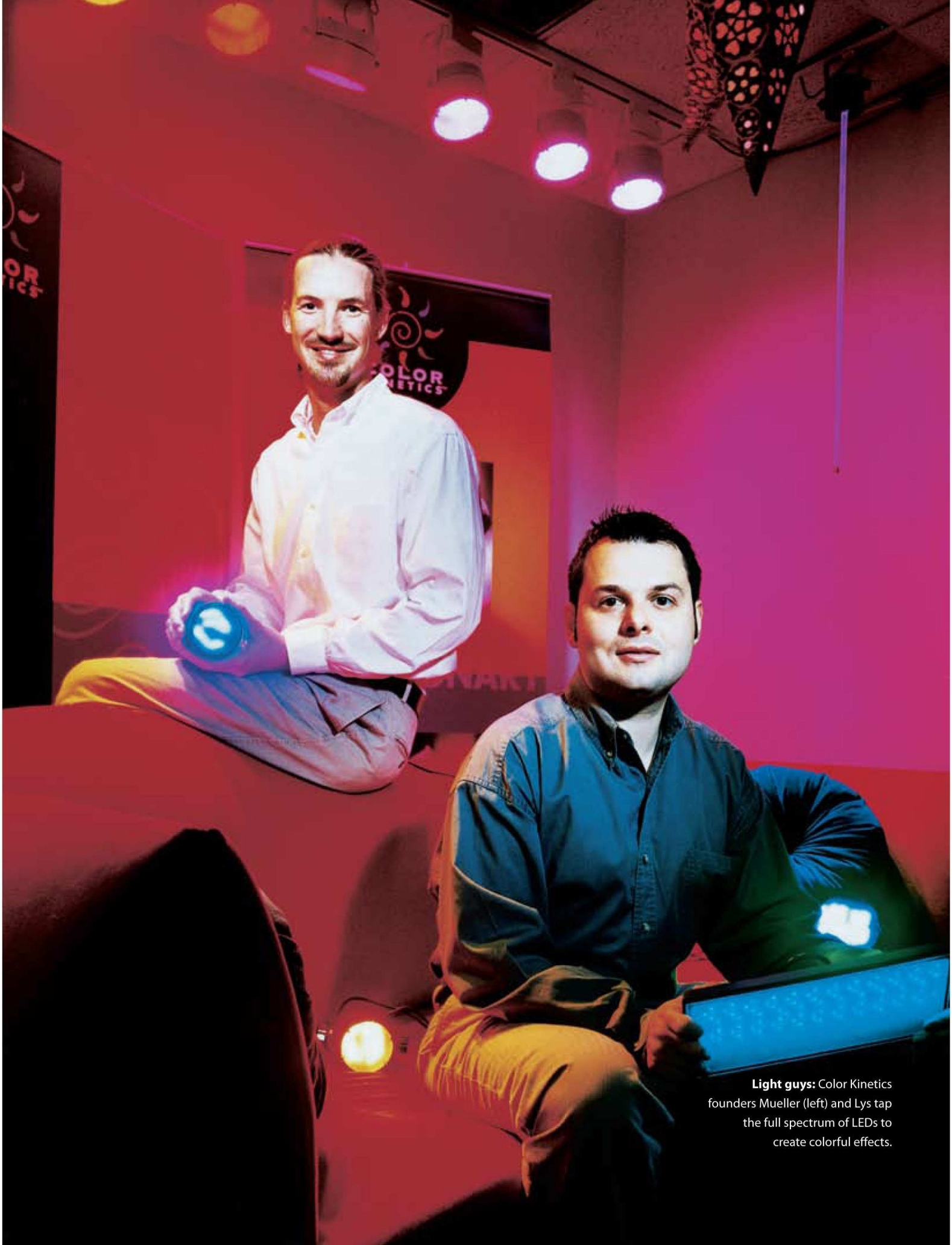
By Neil Savage

A RIOT OF LIGHT ASSAULTS A VISITOR WALKING into the lobby of Color Kinetics on the 17th floor of a downtown Boston office building. Swirled designs on posters change from orange to green, clear plastic shapes glow blue, purple and red in quick succession. And a question soon arises: What color is that couch? It shines cherry red, fades to crimson, turns navy blue, then begins the cycle again.

In fact, the couch is red. It's always red, and only the light shining on it from dozens of tiny spotlights changes, as Color Kinetics demonstrates the effects possible with its digital lights. Each little lamp contains red, green and blue light-emitting diodes (LEDs), which light up in varying combinations under computer control. "We're revolutionizing the lighting industry with what we consider a disruptive technology," enthuses company president George Mueller, tall and ponytailed with the Gen-X standard goatee. "It's a new way to create light."

Mueller and his co-founder, Ihor Lys, have married computer software to a decade of advances in LED technology. LEDs have become ubiquitous in daily life, glowing from the faces of VCRs, clock radios and microwave ovens. But these LEDs have been humble indicator lights on all manner of electronic appliances. Once limited in brightness and stuck at the red end of the spectrum, LEDs have become more powerful in the past dozen years. And a breakthrough in the early 1990s created blue LEDs, suddenly making the whole rainbow available and holding up the promise of white-light LEDs—either by blending the output of colored LEDs or by more exotic techniques. Color Kinetics buys LEDs from device makers such as Agilent and Cree and incorporates them in lamps that give off virtually any color—changing a white wall or a store display from pale green to hot pink at a whim.

PHOTOGRAPH BY SILVIA OTTE



Light guys: Color Kinetics founders Mueller (left) and Lys tap the full spectrum of LEDs to create colorful effects.

Their devices, aimed right now mostly at the retail and entertainment markets, take advantage of some of the special characteristics of LEDs: small size, light weight, low power consumption, nearly infinite selection of colors. But lighting experts say this is only the beginning. Ahead lie entire buildings that light up, traffic lights that last a decade, headlights that won't exhaust your car battery if you leave them on and perhaps even cheap, long-lasting lamps that will drive incandescent and fluorescent bulbs to extinction.

Making Light Work

THOMAS EDISON IS ACCLAIMED, above all else, for inventing the light bulb. While his other inventions—such as the phonograph, the mimeograph and the tickertape machine—have been displaced in recent decades by digital technologies, the light bulb continues to shine on. Now, after 12 decades, technological advances are finally threatening to dethrone it. Anticipating the transition, the major lighting manufacturers are forging alliances with LED makers. General Electric Lighting joined forces with chip-maker Emcore last year to form a lighting division called GELCore, based in Independence, Ohio. Philips Lighting and Agilent Technologies, a Hewlett-Packard spinoff, created LumiLeds in San Jose. And Osram Sylvania has teamed with the semiconductor business of its parent company, Siemens. "You're seeing a big drive by light bulb manufacturers, who are in some sense eating into their own business, but with the recognition that if they don't do it, someone else will," says Makarand Chipalkatti, marketing and technical manager for LED light services at Osram Sylvania in Danvers, Mass.

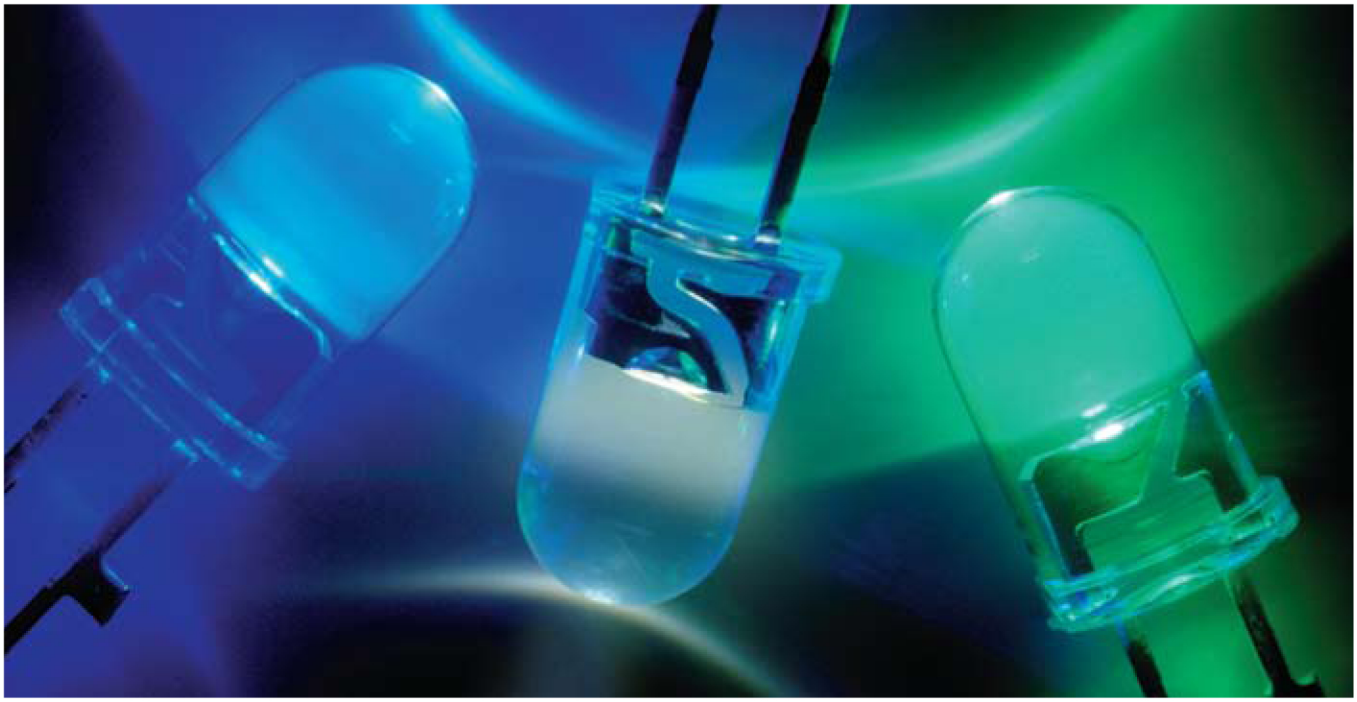
Not all the players in this field, however, are big companies. Startups are getting into the act as well. Mueller and Lys of Color Kinetics met at Carnegie Mellon University, where Lys earned a doctorate in electrical engineering and Mueller majored in computer and electrical engineering, with a minor in fine art. Their first venture into lighting, in 1992, was to build a novelty sign like one Mueller had seen in the Detroit Science Center. A single vertical row of LEDs displayed slices of an image, one column at a time. The human brain, responding as if the viewer's eye were scanning across an unbroken image, would reassemble the picture. The first sign Mueller made said "LOVE"; he gave it to his mother. Then, for the roommates who bet him he couldn't do it, he built a sign that read "BEER."

"We wrote a business plan around it because I was taking business school classes," recalls Mueller. He had three goals for the resulting firm, Stone Age Technologies. The first two were typical student desires: earn some beer money and get a couple of freebies (in this case, free signs). "The third goal was to be on the cover of *In Pittsburgh* magazine," he says, picking through a basket of designer potato chips to find the orange ones. "My new goal is *Rolling Stone*."

"I'll settle for the *Wall Street Journal*," puts in Lys, the shorter-haired, less kinetic half of the pair. The technical guru, Lys is an engineer who, like his counterparts at computer startups, comes to work around noon and stays late.

Although Lys and Mueller came up with the idea for digital lighting in 1993, they put it aside when Mueller and his brother Gary went off to found an economics research firm, Internet Securities, Inc. The brothers sold 80 percent of the Boston-based company last year for $43 million. Mueller disdains the traditional "brass, glass and gas" lighting industry. "It's boring," he declares. "There's no technology involved."

Maybe not, but there certainly is money involved. The United States buys $3.5 billion worth of incandescent bulbs, fluorescent tubes and halogen lamps each year; globally the market is $11.5 billion. So far, the market for bright, visible-light LEDs is relatively puny—about $680 million, according to research firm Strategies Unlimited. But advances in LED technology are moving these devices into an

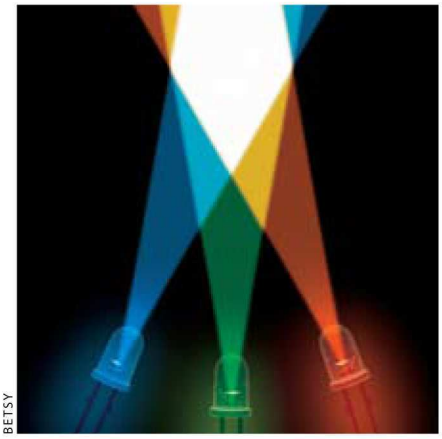


CREE

The blue end of the rainbow: Blue and green emitters combine with older red and yellow LEDs to produce colors on demand.

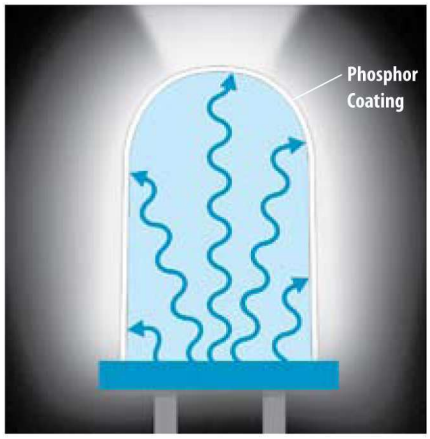
Full Spectrum

Three ways to wring white light from LEDs

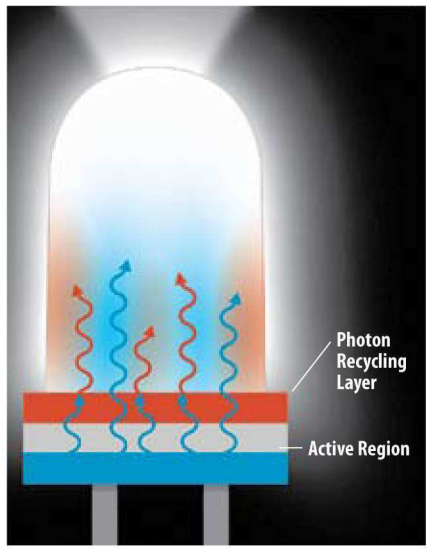


BETSY

Blending beams: **The simplest technique involves mixing the light from multiple single-color devices. Adjusting the beams' relative intensity yields a broad spectrum.**



Phosphor bulbs: **Energetic photons from a blue LED strike a phosphor coating that in turn emits light at a mixture of wavelengths to produce white.**



Light sandwich: **Blue light from one LED device elicits orange light from adjacent layers of a different material. The complementary colors together make white.**

increasing number of applications, and the market is expected to grow to $1.8 billion in five years.

The White Answer

THE FIRST LEDS WERE BUILT IN the early 1960s. The tiny chips of semiconductor material, encased in a clear epoxy, give off a single color of light when electricity runs through them. Negatively charged electrons move to fill positively charged regions in the material, called "holes," where electrons are missing. The combination of an electron and a hole produces a photon of light. The greater the difference in energy between electron and hole—the so-called bandgap—the higher the energy of the photon that emerges. The energy of the photon corresponds in turn to the color of the light; within the visible spectrum, blue and violet photons carry the most energy, orange and red photons the least. Different materials naturally have different bandgaps, so to change the energy level and hence the color of the photons, engineers grow the crystalline semiconductors out of different alloys *(see "They Come in Colors," p. 42).*

High-brightness monochromatic LEDs are already making headway in the marketplace. About 10 percent of the red traffic lights in the United States have been replaced by LEDs. They are more expensive than conventional light bulbs but have other advantages that outweigh the cost issue. One is efficiency: A red LED traffic light uses only 15 watts of electricity instead of the 150 watts consumed by traditional stoplights. Another is longevity—the LEDs are expected to bring traffic to a halt without burning out for a full decade. Single-color LEDs' compactness, low power, intense colors and low heat also have them popping up as car taillights, airplane warning lights on radio towers and runway lights at airports. But the minds of researchers and the eyes of the lighting industry are focused on white.

Lighting eats up one-fifth of U.S. electricity; a change to LEDs would save lots of energy.

And that creates a challenge: How do you get white light out of devices that are, by nature, monochromatic? One method involves mixing LEDs of different colors so they appear white. Just as a television set makes all the colors it displays—including white—out of glowing red, green and blue phosphors, the right combination of LEDs can give the appearance of white. The standard way to mix is with three separate red, green and blue diodes, but the right combination of just two—say blue and orange—can also produce white.

A second method uses an LED to power something else that emits white light. Start with a device made from gallium nitride (GaN), which emits blue light. Coat the inside of its epoxy casing with a phosphor—a material that emits white light when struck by blue or ultraviolet photons. The phosphor thus turns the blue LED into a white-light emitter. (Ordinary fluorescent bulbs work by a similar principle; ultraviolet emission from an electric discharge in the tube causes the phosphor to shine bright white light.) Such devices have become possible only with the arrival of practical blue LEDs; photons at the blue end of the spectrum are more energetic than red ones and have enough punch to trigger a phosphor's emission.

Researchers at the Boston University Photonics Center have recently come up with a white-light diode that combines the mixing and exciting methods *(see illustration, above).* Their "photon-recycling" device essentially consists of two LEDs stacked one on top of the other in the same chip. The bottom LED is made of blue-emitting gallium nitride. This light strikes a layer of a different material—a complex alloy of four materials: aluminum, indium, gallium and phosphorus, or AlInGaP (pronounced "allen-gap"). Some blue photons give up their energy to create orange photons; others

slip through unimpeded. Choosing the right material and the right thickness produces photons that mix to give white light.

Fred Schubert, a professor of electrical and computer engineering at BU and one of the designers of the system, says any color of light should be possible with this setup. He is working on a system that uses differing concentrations of another material—indium gallium nitride—to produce the blue and the yellow. By skipping the AlInGaP layer altogether, this approach would simplify manufacture. That advantage would come at a cost, though. In a multi-chip design, the color of the emitted light could be tuned at will by applying more power to one diode and less to another. In a photon-recycling device, the color is forever fixed by the materials chosen.

The Photonic Squeeze

Whichever methods are chosen to make white light, the LEDs involved have to put out more light and become more energy efficient if they're to replace Edison's bulbs. White LEDs produce about 10 lumens of illumination per watt of electricity consumed, which is comparable to the performance of incandescent bulbs (a lumen is a measure of how brightly the eye perceives light). Roughly 10 percent of the electricity that they consume gets turned into light—marginally better than the 7 to 8 percent figure for incandescent bulbs. But LEDs are still too expensive to challenge your average GE Soft White. On sale at the local discount store, 100-watt incandescent light bulbs run about a dollar for a package of four and deliver 1,500 lumens of illumination apiece. "I cannot make an LED that gives you 1,500 lumens for 25 cents," says Roland Haitz, research and development manager of the semiconductor product group at Agilent. He predicts that in "a few years," his group will be able to make a 1,500-lumen LED that could sell for $150. He doubts the average homeowner will be rushing out to buy such a product.

LEDs made from AlInGaP are pretty efficient at turning electricity into light. About 90 percent of the electrons that enter the diode generate photons. Unfortunately, this semiconductor alloy also has a high index of refraction (a measure of how much a material bends light rays). Instead of shining out for all to see, therefore, most of the photons bounce around the interior of the diode and turn to waste heat; only 30 percent of them emerge as visible light. GaN has a lower index of refraction, so more light escapes from LEDs made from that material. Only 30 percent of the electricity fed into a GaN device is converted to light in the first place, though, so the final efficiency is still only about 10 percent. That's plenty bright for something like a traffic light, but not for general illumination.

This is not an insurmountable problem, says George Crawford, chief technical officer at LumiLeds. Researchers there have been experimenting with new structures of the diodes to let more photons escape. Conventional LEDs consist of cube-shaped crystals. But by arranging the layers of the semiconductor differently and cutting the wafers to create sloping sides, LumiLeds has created an inverted pyramid that results in a shorter optical path for the photons to traverse. In the lab, LumiLeds has managed to get half the photons out of an inverted pyramid LED made of AlInGaP, and they hope to have such LEDs in commercial production this year. "Fifty percent is

They Come in Colors

Early LEDs, made from gallium, arsenic and phosphorus, produced a dim red glow. The structure of the materials dictated that the electrons merged with the holes relatively slowly. As a result, these devices generated only about 0.15 lumens of light per watt of emitted power. By contrast, an incandescent bulb puts out about 15 lumens per watt. By the mid-1970s, LEDs were giving off about 1 lumen per watt, bright enough to light the displays of early calculators and digital clocks. Researchers developed green LEDs made of gallium phosphide—your computer probably has one or several to tell you it's running—but they too were rather dim.

In 1988 came the first red LEDs worthy of the term "high brightness." They were made of gallium aluminum arsenide. The atomic structure of the material allowed the holes and electrons to combine with greater ease, producing brighter light and requiring less electrical power than earlier devices. By 1990, Hewlett-Packard and Toshiba had developed an even better crystal: aluminum indium gallium phosphide. By changing the concentrations of elements in the AlInGaP (pronounced "allengap"), engineers could make bright LEDs that put out red, orange or yellow light.

Blue LEDs remained elusive, however; the materials with the right bandgap were much harder to fabricate. Elements that seemed likely to produce the right bandgap when mixed, such as zinc and selenium, had basic structures that were very different from each other and thus didn't fit together very well. The crystals were hard to grow in the first place, and even when they did work, they tended to fracture and grow dark when electricity was applied.

At Nichia Chemical Industries, a small Japanese company that makes the phosphor coatings for the inside of computer and television screens, an unknown researcher named Shuji Nakamura decided in 1988 to tackle the problem. He chose gallium nitride (GaN) as his material, mostly because no one else was working on it. With the blessing of the company's president and a generous research budget, Nakamura developed a way to grow GaN crystals that could survive the energy input needed to produce blue light. By 1994, Nichia was selling the blue LEDs, quickly followed by bright green devices created by mixing the right amount of indium into the GaN. This development gave LED users the entire rainbow at their disposal—and a bright rainbow at that. More important, white light was now within reach.

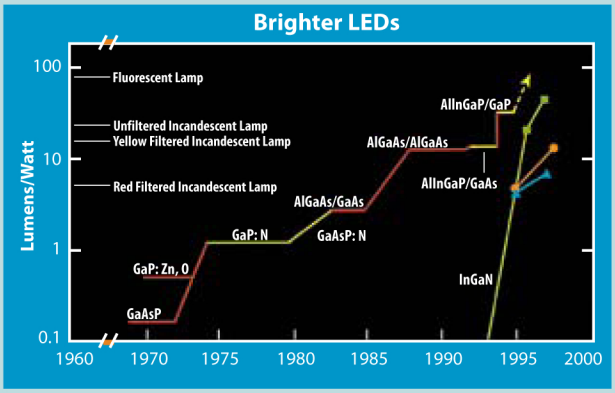
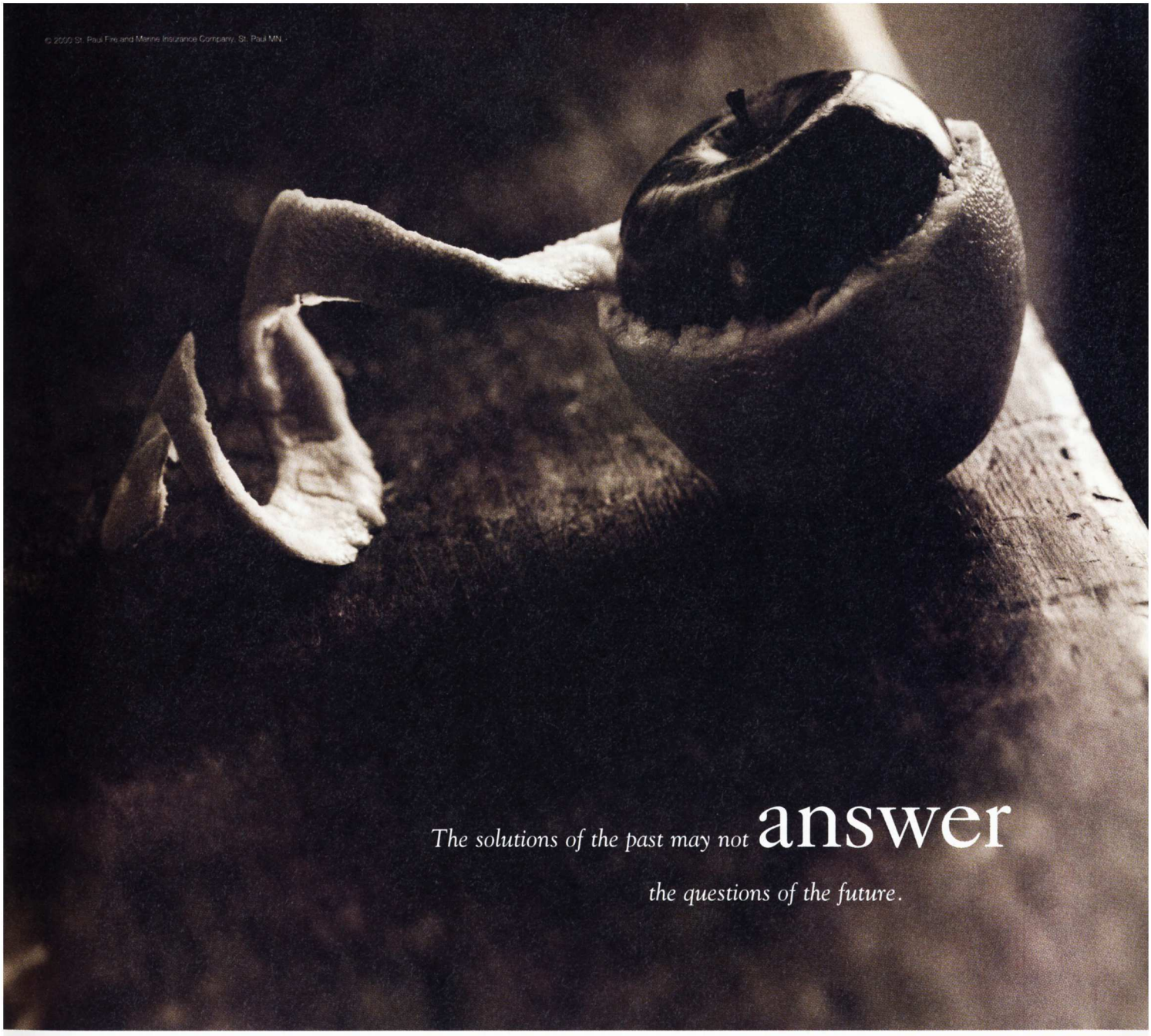


ILLUSTRATION: BETSY HAYES; SOURCE: LUMILEDS LIGHTING



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CREE; COLOR KINETICS; OSRAM SYLVANIA

Lighting up: New LEDs make efficient taillights (left), bright fixtures (middle) and marker lights for walkways, stairs and seating.

plausible, but hard," Crawford says, but adds: "It's hard for me to envision doing much better than that."

Getting half the photons from AlInGaP may be enough to compete with fluorescent lights, but not by itself. Devices made of that material provide only the red and yellow light. The complementary blue photons needed to produce white light must come from gallium nitride, and there the technology is still embryonic. "We really don't understand the fundamentals of how to build a better crystal in gallium nitride," says Steve Johnson, leader of the lighting research group at Lawrence Berkeley National Laboratory.

Researchers are looking for a shot of government funding to help their quest. Arpad Bergh, president of the Optoelectronics Industry Development Association, wants a major R&D effort to bring LEDs to the point where they can compete with traditional light sources. His group is working with Johnson at Lawrence Berkeley to develop a research plan for more efficient white-light LEDs and intends to ask Congress for a five-year, $50 million per year funding program that would start as soon as 2002. Meanwhile, Haitz has written a white paper with Sandia National Laboratories calling for the government to pour $500 million into research over 10 years. Such an expenditure is needed, Haitz argues, to lift LED lighting over the hurdles that are now impeding progress. Left on its own, he argues, the lighting industry will advance LEDs only enough to take about one-tenth of the lighting market by 2025. But with government help, he says, the devices could by that year account for half the market. Because lighting accounts for about 20 percent of the electricity consumed in the United States, a shift to the more efficient LED technology could render significant energy savings.

An Eerie Glow

But if LEDs are to capture a large share of the illumination market, they will have to produce light with the right tone. As anyone who has ever taken an indoor picture with outdoor film knows, incandescent light has a strong yellow cast, and designers say it has a warm feel. White phosphor LEDs, on the other hand, emit a distinctly bluish glow. "If you're trying to illuminate a red object with a white LED that only has blue and yellow in the spectrum, you're not going to get a very nice-looking red," warns Kathryn Conway of the Lighting Research Center at Rensselaer Polytechnic Institute. That can be a problem with human skin, for instance, which looks unnatural under light that doesn't approximate daylight. Renowned New York lighting designer Howard Brandston points out: "You don't want someone to wake up in the morning and look in the mirror and say, 'Egads! I could audition for "The Addams Family" without makeup.'"

But the technology will definitely keep improving, since the payoff is large—in part because with LEDs, you'll be able to turn a dial to get lighting with just the right feel for the situation at hand. Brett Andersen, a senior designer at Focus Lighting, a New York-based lighting design firm, envisions a day when people will be able to set the color and brightness of the light in their homes according to their moods. This kind of control will make the old-fashioned dimmer switch a primitive tool for creating ambience. Beyond that, LEDs offer new possibilities that raise more fundamental questions about how people think about lighting, says Chipalkatti of Osram Sylvania. "How would things look if the building itself was a light fixture?" he asks. "You could have your floor or your ceiling light up."

In the offices of Color Kinetics, software writer Mike Blackwell sits on the chameleon couch and demonstrates the program he's developed for lighting designers to create effects with the company's lights. He sets a row of lamps to run through the spectrum, repeating the cycle every 10 seconds. Then he adds a white pulse that moves down the row once a second. The effect is jarring, reminiscent of the psychedelic light shows of the 1960s. It also suggests artifacts of another era: those desktop-published newsletters of the mid-1980s, brimming with clashing fonts. But if lighting designers are right, more sophisticated users will be able to create subtler effects or repaint their walls with light. And perhaps the incandescent bulb will join an earlier lighting standard, the candle, as a quaint accent for special occasions, while our days and nights are lighted in the glow of tiny chips. ◊

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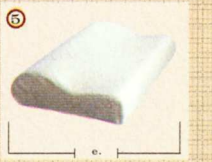
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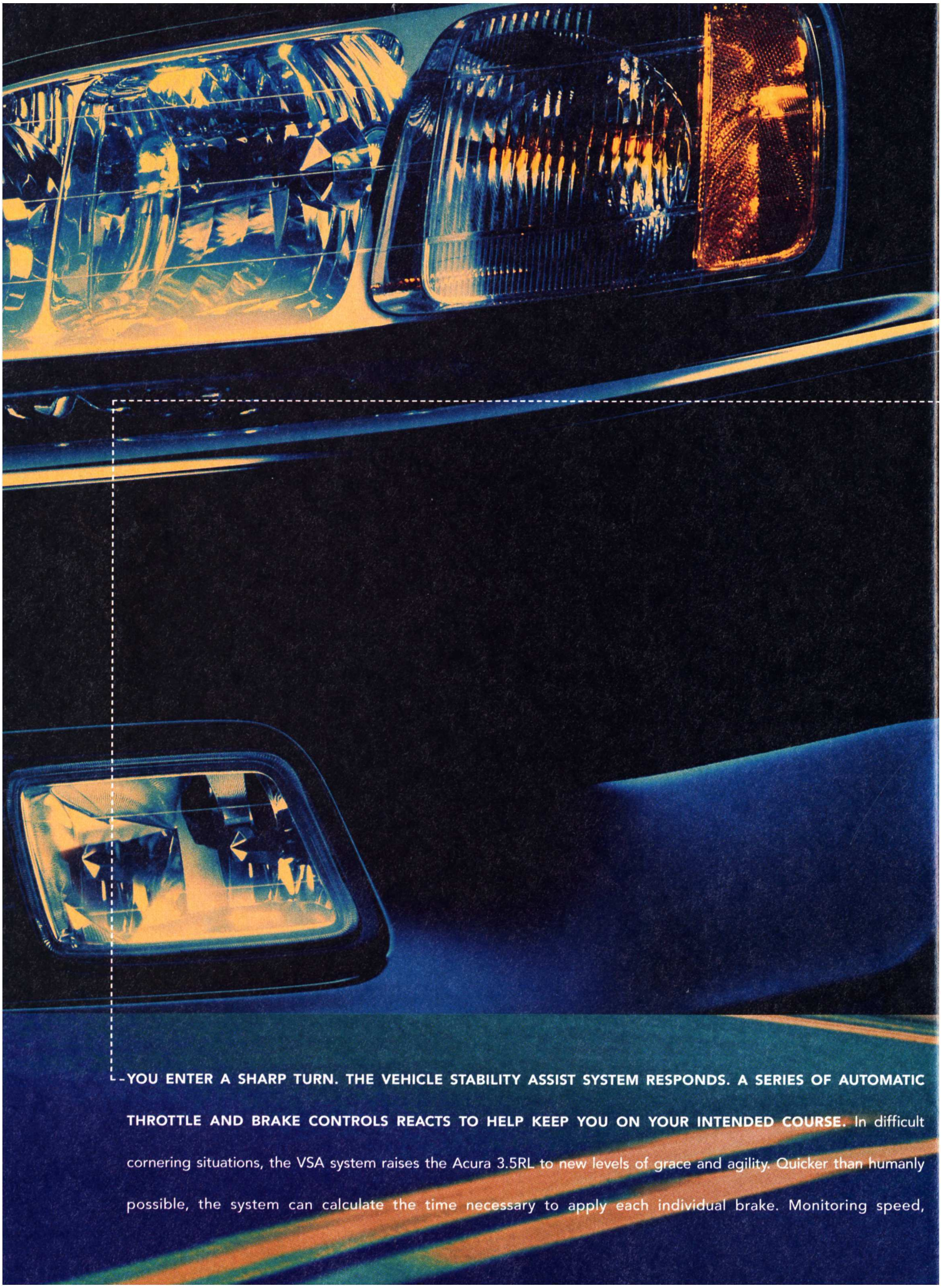
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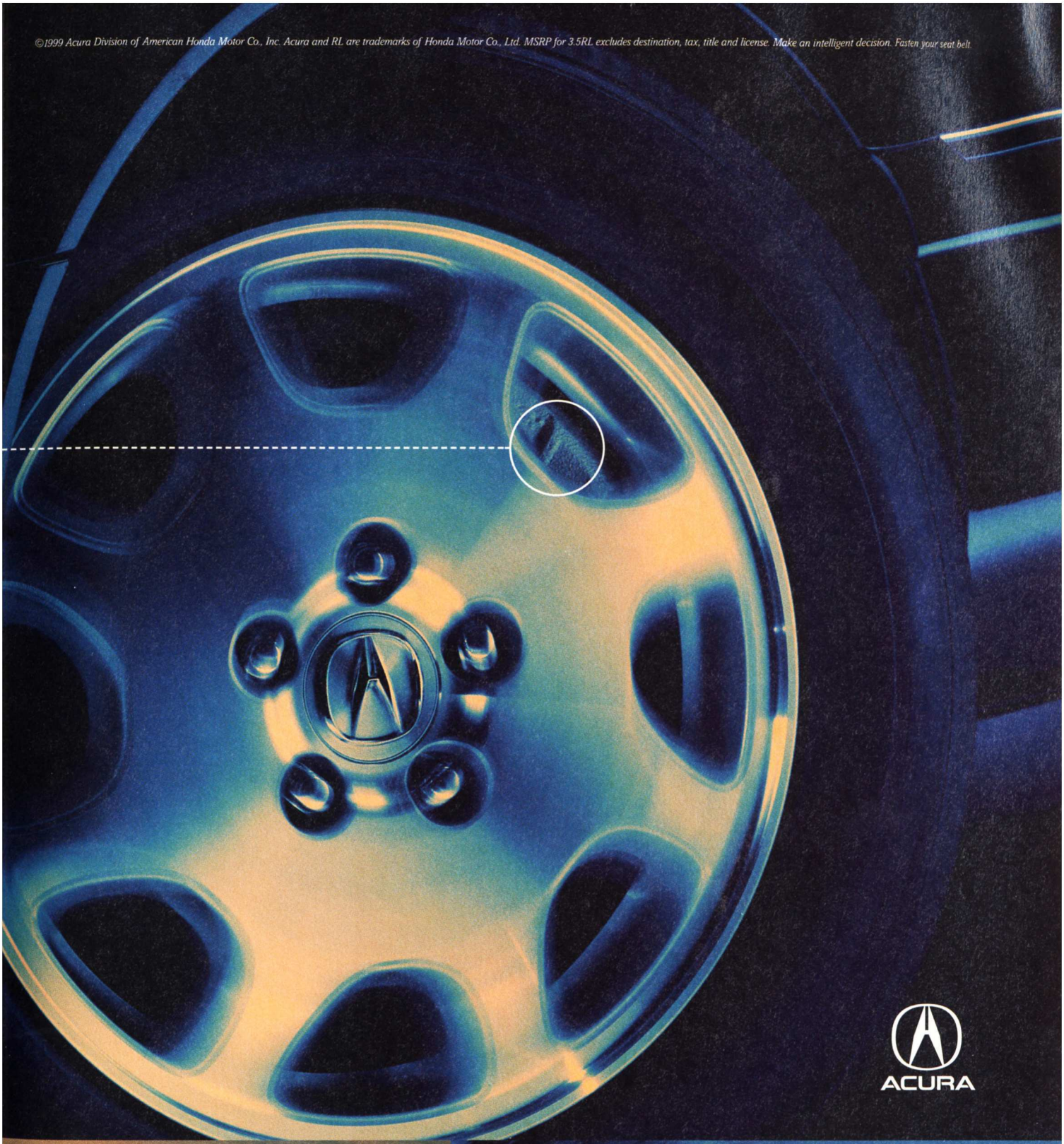
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Biotech companies are snapping up patents on human genes. Will the trend mean powerful new medicines, or will it quash biomedical innovation?

The Great Gene Grab

IMAGINE THAT WHEN NEIL ARMstrong stepped onto the lunar surface for the first time in July of 1969 to plant the American flag and proclaim "one giant leap for mankind," he found that a number of companies and universities had gotten there first and divvied up the moon for themselves. Not only had they quietly laid claims to the most promising parcels of lunar real estate, but they had done so with the blessings of the U.S. government.

Sound absurd? Well, that's the fate of the 10-year, multibillion-dollar effort to decipher the human genetic code. In June, amid much fanfare, the directors of the publicly funded Human Genome Project and executives at Celera Genomics, a Rockville, Md.-based startup, announced they had separately finished sequencing most of the three billion DNA letters that comprise the human genome—the so-called "Book of Life." This rough draft of the human genome, the leaders of the decade-long public effort proclaimed proudly, represents an invaluable

BY ANTONIO REGALADO PHOTO-ILLUSTRATIONS BY JANA LĒON



resource free for use by all humanity in its quest to diagnose and cure diseases.

The only problem is that numerous passages (and many of the most interesting sections) in this Book of Life have already been staked out as private property. Even as the Human Genome Project and Celera competed to finish sequencing the genome, a separate race was well under way: a race to patent as many human genes as possible. The frenzied patenting effort, taking advantage of the same automated sequencing technology and high-powered computers that made the Human Genome Project possible, has been spearheaded by a handful of "genomics" companies, high-tech startups whose laboratories are uncovering genes by the fistful—and whose legal departments are filing patent applications almost as fast.

Human Genome Sciences of Rockville, Md., which has been aggressively filing its claims since 1994, holds patents on 103 human genes, including those believed to be responsible for osteoporosis and arthritis; it has patents pending on another 7,500 genes. Incyte Genomics of Palo Alto, Calif., tops the list with some 400 patented genes, while Celera, which only began decoding DNA last year, has already filed patent claims on at least 6,500 gene sequences. Universities and government agencies are also involved: The University of California and the National Institutes of Health are among the most active gene patenters *(see "Gene Patent Fever," p. 55)*.

"The patenting is intense," says Mark Boshar, associate general counsel at Millennium Pharmaceuticals, a genomics firm in Cambridge, Mass. Boshar says the reason for the frenetic pace is simple: "There is one human genome and a finite number of genes." The number of human genes is likely somewhere between 50,000 and 150,000 (geneticists are still debating the actual number). Of those, about 1,000 have already been patented, and applications on thousands of others await approval.

It's not a stretch to say that what's at stake in this unprecedented patent grab is the future of health care. From diagnostic tests that can spot the telltale changes in a cell before a cancer begins to grow, to DNA microchips that someday may provide a complete readout of a person's genetic virtues and flaws, to a new generation of drugs that compensate for shortcomings in a patient's genetic material, there are few aspects of medicine that will not be affected by our emerging knowledge of genes.

Despite the high stakes, the administrative apparatus that oversees the patenting process is surprisingly spare. One agency is largely responsible for the entire process: the United States Patent and Trademark Office. And although gene patenting procedures have been roundly criticized by insiders as flawed *(see "New Patent Rules Pending," p. 53)*, there has been little public debate on the matter. In fact, no congressional vote or Supreme Court decision has ever directly addressed the question of whether human genes should be patentable at all.

How can anyone "invent" and patent the genes that each and every one of us has carried since birth?

This public silence, however, is ending. Many scientists and lay people believe the knowledge of human genes and how they work ought to be public property, like the Grand Canyon or the theory of relativity. Physicians and scientists are complaining that the thicket of patent rights is already stifling biomedical research—and even interfering with the care of patients. Even for those in the pharmaceutical and biotech industries who readily embrace intellectual property protections, a nagging question remains: Is today's deluge of patents on human genes really good for innovation?

Man-Made Genes

DURING A DECADE AND A HALF OF LECturing on biotechnology law, University of Michigan legal scholar Rebecca Eisenberg says she's been asked the same question countless times: How can anyone "invent" and patent the genes that each of us has carried since birth? Although patent law allows inventors to claim new and useful machines, processes and compositions of matter (say, the chemical recipe for a novel plastic) as proprietary creations, that privilege traditionally has not extended to "products of nature," such as the elements in the periodic table. However, when it comes to human genes, says Eisenberg, legal precedent offers a way around that prohibition, namely that genes captured and identified in the lab aren't in their natural form. In order to be studied, genes are copied, abbreviated, spliced into bacteria or otherwise altered. From the point of view of patent law, a gene is just another man-made chemical.

Using that logic, the U.S. Patent Office began issuing the first patents on human genes in the 1970s. Since then, gene patents have become the bedrock of the burgeoning biotech industry. Human growth hormone, insulin and erythropoietin—protein drugs with billions of dollars in combined annual sales—are all manufactured using patented DNA sequences. Given the incentive of 20-year patent protection, several dozen new drugs have been brought to market (with hundreds more in the pipeline) by a U.S. biotech industry that now numbers 1,200 companies and counts $13 billion in sales, according to the Biotechnology Industry Organization (BIO), a Washington, D.C., trade group. "No one would develop a drug if you didn't have a patent," says Human Genome Sciences CEO William Haseltine *(see "The Case for Gene Patents," p. 59)*.

But critics counter that the current patent grab is decidedly different, driven less by an expectation that a specific genetic sequence will lead directly to a new drug than by the speculation that if you are able to patent enough DNA sequences, somewhere in that haystack there will be some genetic needles of value. What's really being patented today, critics argue, aren't manufacturing methods or even useful molecules, but basic scientific findings.

These transformations in patenting practices have largely been driven by changes in the technology itself. Starting in the early 1990s, automated DNA-sequencing machines gave researchers the ability to identify genes easily and cheaply. As a consequence, genomics companies have sprouted up to patent gene sequences, often without any clear idea what useful purpose the sequences will serve. In other cases, where a gene's function is known,

biomedical researchers are frustrated by what they perceive as patenting of basic scientific knowledge, such as the fact that a certain genetic mutation causes a disease. Yet it is precisely these types of patents that are helping to drive today's booming genomics sector, where the main product is information and where intellectual property is sometimes the only real asset a startup company has. But, says Eisenberg, the trend also raises a fundamental question: "Can information about the natural world, as distinguished from tangible human interventions that make use of that information, be patented?"

Super Patents

LAST APRIL, BOTH THE IMPORTANCE AND potential dangers of the coming wave of gene patents became clear when the University of Rochester was granted a patent on a gene called Cox-2. University officials immediately filed a lawsuit against G.D. Searle, a subsidiary of Pharmacia, whose blockbuster painkiller Celebrex acts by blocking the enzyme encoded by the Cox-2 gene. Rochester claims Searle's drug infringes its patent, which describes not just the DNA letters of the gene, but also the general idea of using a drug that blocks Cox-2 as a way to alleviate pain.

The financial stakes are immense. Dubbed "super aspirin," Cox-2 inhibitors are the hottest new pain drugs. In 1999, its first year on the market, Celebrex logged $1.5 billion in sales and eclipsed Pfizer's potency miracle Viagra as pharmacies' fastest-selling pill. (Merck of Whitehouse Station, N.J., also makes a Cox-2 inhibitor called Vioxx but is not named in the suit.) A University of Rochester press release giddily predicted the university's patent is "likely to be the most lucrative in U.S. history."

The case highlights several troubling aspects of gene patenting. As a tactic to pressure Searle into paying royalties, Rochester has asked a judge to force the company to take the drug off the market, despite the fact that it is used by nearly seven million people, many of whom suffer from severe arthritis. The case also raises new and difficult questions about what a patentable "invention" really is. Is it Celebrex, a drug developed by industry at a cost of millions of dollars? Or is it the knowledge of Cox-2's role in pain and inflammation, a fundamental scientific discovery paid for with federal research monies?

Gerald Dodson, a litigator Rochester has hired from the firm Morrison & Foerster, says, "If you discover something that opens a new area of research, then it should be patentable. That is what's at the heart of this. Somehow there is a school of thought that different rules should apply to basic research in medicine, and I don't think that washes under any kind of scrutiny. "

Searle freely admits it used scientific findings about Cox-2 as the starting point for its hunt for a drug. (The Cox-2 discovery has also prompted drug research aimed at treatments for Alzheimer's disease and cancer.) But Searle lawyers say the Rochester patent is invalid because it doesn't give precise enough directions for finding a drug. In the parlance of patent law, Rochester's claim qualifies as a classic "submarine patent": a broad early claim that quietly sits at the Patent Office only to surface when another inventor's work gives it commercial significance.

Whether or not the University of

One-Clicking the Genome

What bearing could a patent fight between online booksellers have on genome research? Quite a lot, as it turns out.



Last year, Amazon.com successfully sued Barnes & Noble for copying its patented "one-click" method of selling goods online, sparking debate over a new wave of patents on Internet business methods *("Software Patents Tangle the Web,"* TR *March/April 2000).* Spurred by a 1998 court decision, dot coms have been scrambling to patent all sorts of novel (and sometimes not-so-novel) ways of doing business online—everything from methods for hawking music to conducting Web-based auctions. Next up for online commerce: the human genome.

One entrepreneur, who requested anonymity, described a "silent gold rush" as firms move to file patents staking out methods for sharing and manipulating the enormous quantity of genetic data being put online. Such approaches will be increasingly important to genomics, as scientists begin to "annotate" the raw DNA sequence with clues to gene function and other information. The entrepreneur interviewed by *TR* described one recent patent application that claims the idea of using a rewards system to compensate scientists with free purchases for posting information and comments to a private gene database.

One company looking to use such patents to protect its business model is DoubleTwist.com, an Internet startup in Oakland, Calif., that has teamed with Sun Microsystems to annotate information from GenBank, the public-sector database of human DNA. Robert Williamson, DoubleTwist's chief operating officer, says the company is filing patents "around the software, the data processing, the data mining...the things that take you from the raw stuff to the good stuff."

No one is sure how important these new intellectual property claims will be. However, legal circles are abuzz over patents like No. 5,966,712 (entitled "Database and system for storing, comparing and displaying genomic information") that was issued to Incyte Genomics last fall and appears to describe a basic way of using computers to study genes.

When *TR* provided a sampling of similar patents to Mark Gerstein, a bioinformatics researcher at Yale University, he expressed surprise. Gerstein says the methods described didn't appear to be new, a complaint often levied against software patents. "These patents in a sense also represent a patenting of a scientific method—a way of doing science. Does that make sense?" asks Gerstein. If the new gene-commerce patents make as big a splash as Amazon's did, it's a question many more people will soon be asking.



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Rochester deserves royalties from every Cox-2 inhibitor on the market, the surfacing of more and more genetic submarines could signal a painful future for drug development. All existing drugs on the market act on only about 400 distinct targets in the body; these are the critical enzymes and pathways that can be addressed in treating various diseases. And scientists' best guess is that there may be only 5,000 "druggable" targets overall. As they reveal these targets, companies and universities are laying claim to what amounts to the ultimate biological monopoly—patents that comprehensively cover not only a gene and the protein it makes, but also any "method of treatment" that specifically targets them. Already, Pfizer has a patent in Europe covering any drug that acts via PDE5, the protein targeted by Viagra.

At Millennium Pharmaceuticals, such "methods of treatment" claims are what Mark Boshar calls the "crux" of his company's patent strategy. Millennium has dozens of such claims pending at the Patent Office, including several on human obesity genes that could be the basis for a new generation of diet drugs. According to Boshar, these patents are a just reward for innovative research that is uncovering the true molecular causes of disease for the first time. The only type of protection broad enough to protect such a fundamental insight, he says, is one that renders the target "locked up and protected... regardless of the drug that our competitor develops."

Few patents are likely to be as wide-reaching as the one on the Cox-2 gene. In fact, the majority of gene patents, just like most new golf ball designs (another popular category at the Patent Office), will end up being worth little or nothing. However, the sheer number of pending patents could present its own problems. In a 1998 paper in the journal *Science*, Rebecca Eisenberg and Michael Heller, a University of Michigan colleague, warned that a proliferation of early-stage intellectual property rights could end up stifling lifesaving innovations. For instance, drug companies might shy away from working in a particular area because it's strewn with overlapping claims on basic scientific building blocks.

One way around this problem would be for companies to share their patents to make new drugs possible. That's what's happened in the computer industry, where PCs make use of hundreds of patents, held by a wide array of different inventors. But Iain Cockburn, an economist at Boston University, says that despite the attractive nature of such sharing, particularly where human health is concerned, it may be hard to achieve in biotech. "The nature of the biotech industry is the potential cause of some problems. There are a lot of small, hungry companies out there whose only asset is intellectual property. It's less likely that broad cross-licensing agreements can happen. If you have too many people owning small, overlapping slices of the same pie, there could be a breakdown."

Showdown in Genetown

MOST OBSERVERS CONCEDE THAT BOTH private rights and the public good need to be balanced in some way. The question is how. Will market forces afford a solution, or will the courts and policy-makers be forced to step in, breaking up gene monopolies in the name of society? Many would like to see the market work its wonders. But in the near term, it's the opinion of Q. Todd Dickinson, director of the Patent Office, that "those who own the genes have a heavy responsibility that they are used for the good of all mankind."

Service to humanity is a nice idea. But it's already breaking down in a mounting dispute over genetic testing. Discoveries of the gene mutations that cause inherited diseases or susceptibility to cancer have been among the first practical payoffs of genomics research. But now physicians at academic medical centers around the country are complaining bitterly that stiff fees and onerous licensing terms are prohibiting them from performing diagnostic tests.

For instance, biomedical researchers at the Miami Children's Hospital in Miami, Fla., helped discover (and then patented) the mutations that cause Canavan disease, an inherited neurological disorder that affects Ashkenazi Jews. The scientific advance allows doctors to test parents who fear they might be carriers of the defect by taking blood samples and checking for specific DNA mutations on chromosome 17, where the Canavan gene is located. The catch? Miami Children's is charging a $12.50 royalty for every test performed.

Physicians are balking at having to pay to use what they consider to be medical knowledge. The financial restrictions,

New Patent Rules Pending

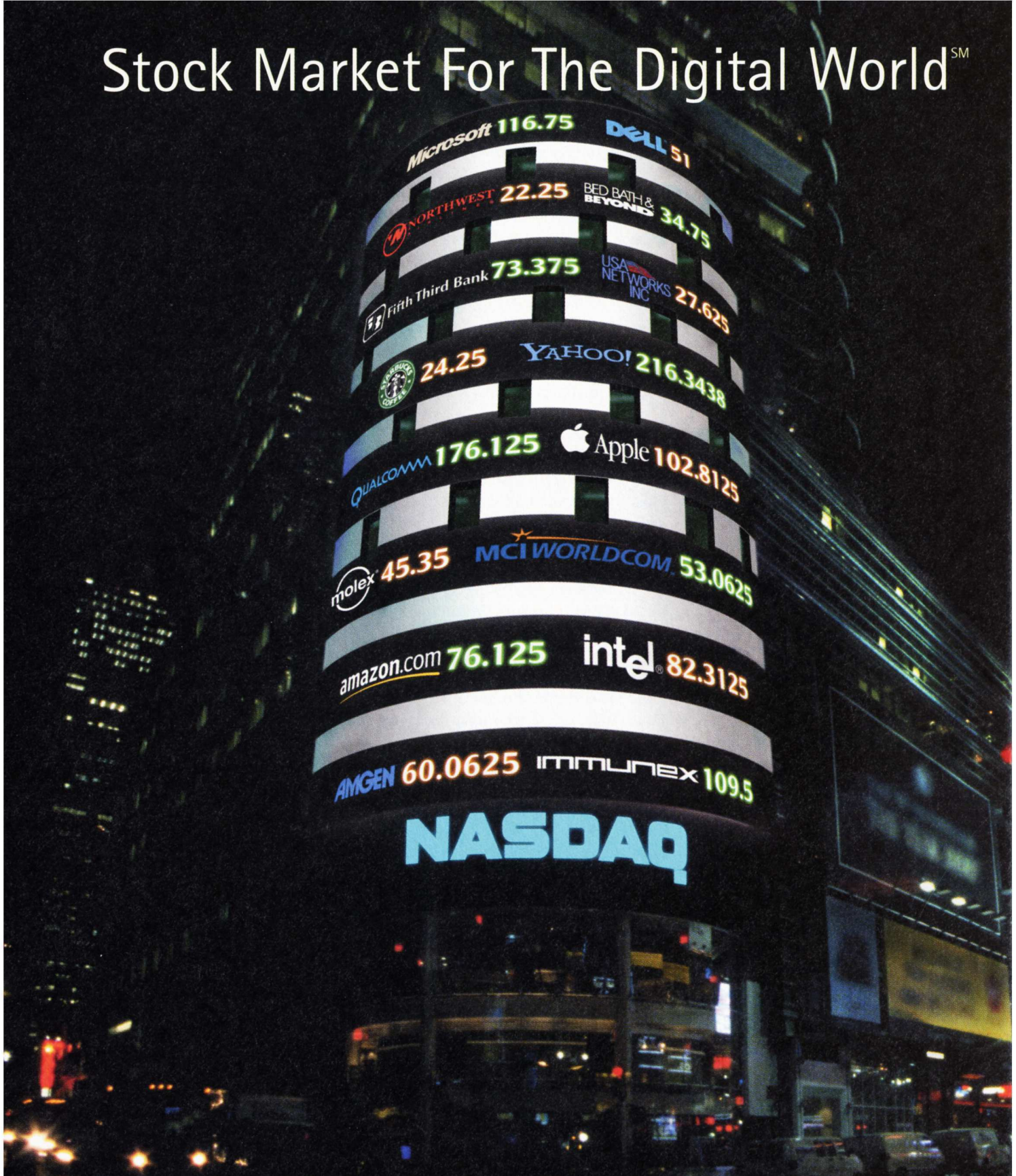
Are patents on human genes too easy to win? In general, any invention must be deemed novel, useful and non-obvious to earn a patent. It's on the second requirement of "utility" that gene patents have run into trouble.

Starting in the early 1990s, new technology for decoding DNA allowed the rapid discovery of gene fragments known as expressed-sequenced tags (ESTs). Although the biological functions of these DNA sequences (much less any specific medical payoff) were still unknown, companies gambled on a legal loophole; they proposed generic and often frivolous uses—as forensic probes, even cattle feed.

Leading academics and bosses at the National Institutes of Health have long opposed EST claims, arguing patent rights should be reserved for whomever uncovers the true biological function of a complete gene. Now, after years of delay and plenty of behind-the-scenes wrangling, it appears that the U.S. Patent and Trademark Office agrees—at least partly. Under new guidelines in development, patent examiners will be directed to reject patents that don't describe a "specific, substantial and credible" use for a DNA sequence.

While that decision dooms thousands of pending EST claims, the utility controversy rages on. Critics are now vigorously opposing patents that finesse the utility requirement using results from computer programs that can guess at a DNA sequence's likely function based on similarity to known genes. In a letter to the Patent Office, Bruce Alberts, head of the National Academy of Sciences, complained: "Those who would patent human DNA sequences without real knowledge of their utility are staking claims not only to what little they know... but also to everything that might later be discovered about the genes."

With many details of gene patenting still in dispute, the Patent Office says it is now looking for guidance from a higher authority—the federal courts.



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they argue, hurt their ability to teach, perform research and care for patients. "We would be happy to pay for some kind of test kit that is faster, better, cheaper. But they are trying to control manual testing, which is not appropriate," says Michael Watson, a professor of pediatrics at Washington University in St. Louis.

The Canavan test is not the only one that's kept behind a patent wall. Companies with patents on genes that can predict the onset of breast cancer and Alzheimer's disease have angered physicians by exercising their right to keep commercial testing in-house. Tired of receiving letters bringing news that yet another gene has been patented—and that it's time to pay up—Watson is among the physicians pushing for strong action. After tipping off the press to the controversy, he helped draft a resolution endorsed by the American College of Medical Genetics that calls for a moratorium on human gene patenting. The resolution is now being considered by the American Medical Association, which has supported gene patents in the past.

With patient groups and physicians rallying against gene patents, the trade group BIO has moved to stem the growing public relations debacle. In an interview, Chuck Ludlam, BIO's VP of government relations, offered dire warnings. "Any move that compromises issuance of patents on genetic tests could have an impact on drug research. They are not separable. If there is an idea around of changing the law or the licensing on diagnostics, I think that is dangerous and misguided."

Watson quickly dismisses the argument. "They [the biotech industry] talk about saving the children, but their angst comes primarily from the loss of market valuation. I don't think that our side has a whole lot of interest [in] coming to an agreement."

With the rhetoric from both sides heating up, the dispute over diagnostics could be a warning sign that commerce and medicine just can't get along when it comes to gene patents. Diagnostics "is where the shooting is going to be for the next few years," says University of Pennsylvania bioethicist David Magnus. "This is the cutting edge of the clash of values between the business world and the scientific and medical worlds."

My Genes

THE CONCERN ABOUT WHO OWNS COMmercial rights to our genetic material is manifest high and low. At the highest levels of the National Institutes of Health, deep ambivalence about patenting has shown itself in health officials' ongoing efforts to convince the Patent Office to make gene patents more difficult to secure. At the National Academy of Sciences, gene patents have been included in a new study, "Intellectual Property in the Knowledge-Based Economy," that is intended to determine whether the patents help or hinder innovation. And activists associated with the well-known biotech critic Jeremy Rifkin say they are planning a legal challenge to gene patents that they hope to take all the way to the Supreme Court.

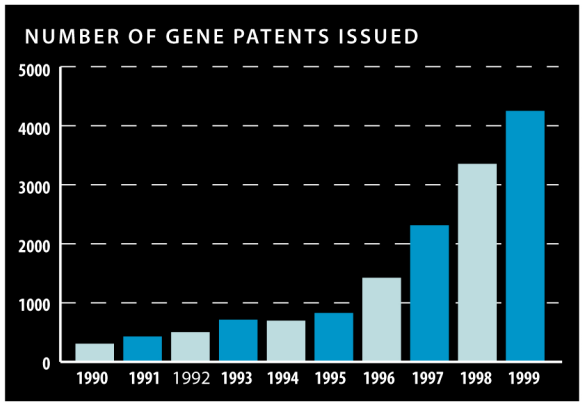
That's in the towers of Washington. In the streets the issue is also heating up. Over seven days last March, Boston played host to both the largest-ever biotech industry conference and the largest gathering of anti-biotech protesters in North America. One genomics company CEO, Jonathan Rothberg of CuraGen in New Haven, Conn., describes taking off his nametag and venturing across the police barriers that separated the industry proceedings from the colorful crowd of protesters. Rothberg says he was troubled by what he heard. "I spent the day with the protesters. I'd say 90 percent were worried about genetically modified food, and 10 percent were worried about people patenting their genes," says Rothberg. "I watched the genetically-modified food debate tilt in the wrong direction. I look at our own industry and I realize that we are causing undue anxiety."

Could it be public opinion that ultimately determines whether gene patents actually promote the creation of new medical treatments? "This subject is not going to run away, and at the end of the day the general public is potentially going to get involved in this if they feel the system is being used unfairly," says Michael Morgan, chief executive of the Wellcome Trust's Genome Campus in Cambridge, England. "The ownership of 'my genes' is an emotive rallying call for all kinds of folks, and we need to be aware of that or we are going to hinder the development of new drugs."

Although gene patenting has been going on for years, as far as the man and woman on the street are concerned, the debate has just begun. And if it follows the course of other recent biomedical controversies over cloning and stem cell research, it may be one argument that politicians and ordinary citizens will not be content to leave in the hands of scientists, pharmaceutical companies or patent lawyers. ◊

Gene Patent Fever

The number of gene patents granted each year has shot up almost 14-fold since 1990. Data include patents on human, animal, plant and microbial gene sequences.

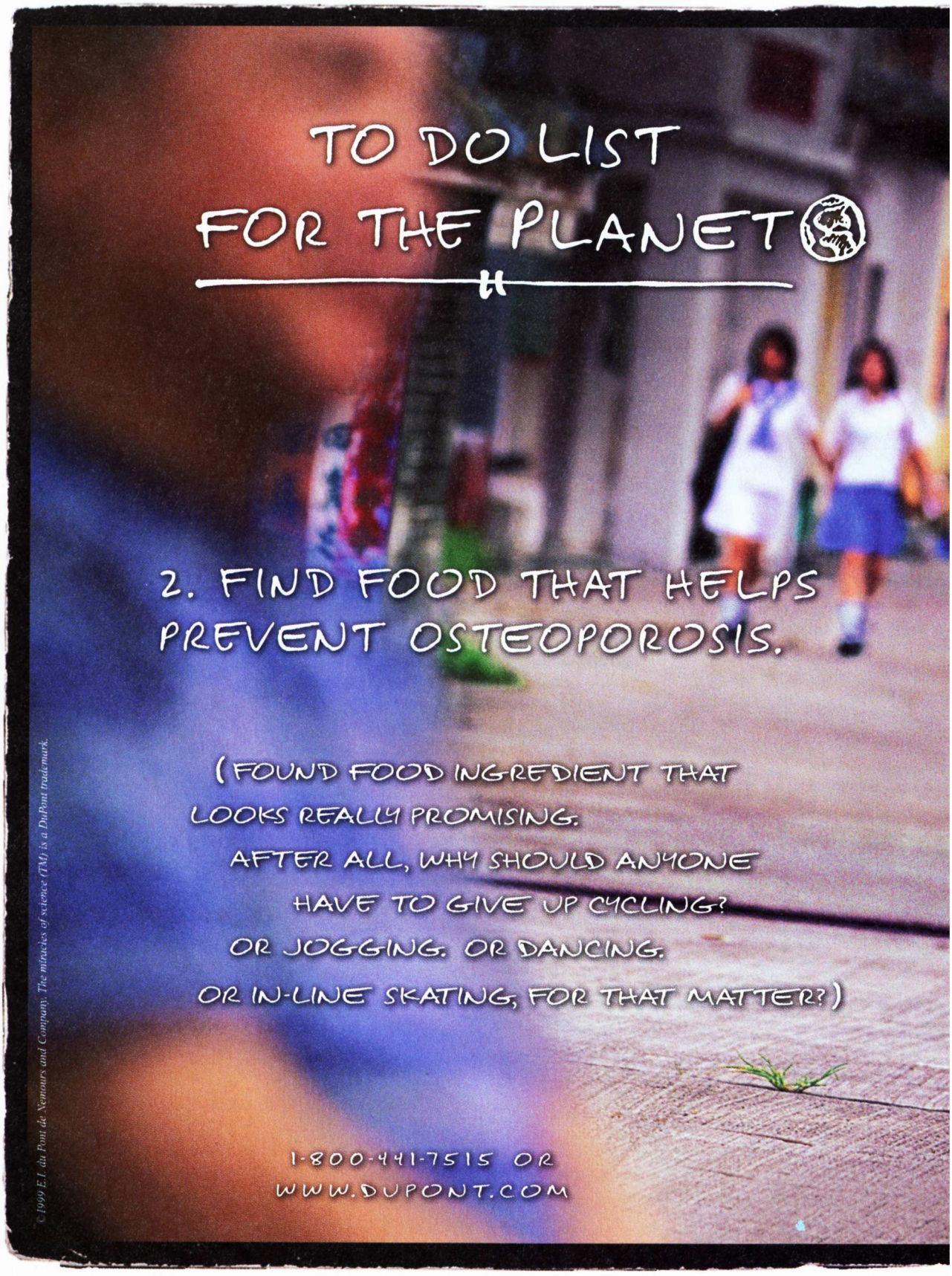


SOURCE: STEPHEN MCCORMACK, ROBERT COOK-DEEGAN AND LEROY WALTERS

TOP 10 PATENT HOLDERS	
Incyte Genomics	397
University of California	253
Glaxo SmithKline	248
U.S. Dept. of Health & Human Services	205
Novo Nordisk	196
Genentech	165
Isis Pharmaceuticals	146
Chiron	135
American Home Products	130
Novartis	128

Data current through 6/28/00

SOURCE: U.S. PATENT AND TRADEMARK OFFICE



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The Case for Gene Patents

THE CONTROVERSY OVER GENES AND patents has exposed widespread public confusion over the relevant meaning of both. Apparently, some people mistake patents as ownership rights and see genes only in their broadest possible context as instruments of heredity.

A patent is a social contract between society and an inventor, originally developed by the Venetians to promote trade and commerce and avoid the accumulation of trade secrets. Today, society grants patents that assign to inventors exclusive commercial rights for their inventions provided they meet all these criteria:

- An invention must be novel and not obvious. It cannot be known or deduced directly from prior knowledge.
- An invention must be useful—knowledge itself cannot be patented.
- A patent must enable others to use the invention by providing specific directions.

The patent system is thus structured and administered to assure the rapid and open dissemination of new knowledge, encourage innovation and promote commerce. In Abraham Lincoln's words, patents "couple the fuel of interest to the fire of genius."

Nowhere are patents more central to the creative process than in genetic drug development, where human genes and their expressed proteins themselves are developed as therapies. The biotechnology industry in the United States has brought a handful of these crucial new products (recombinant human insulin, to name one of the most familiar) to market and is on the threshold of a bonanza of genetic drugs and vastly greater relief for ill and aging populations around the world.

Patent protection is the *sine qua non* of that bonanza. Discovering and developing a new gene-based pharmaceutical product in the United States requires years of commitment and immense capital resources—as much as $500 million. Without the possibility of recouping investment that is bestowed by patents, no biotechnology company would be able to raise the financing necessary to develop these products.

Recently there has been a surge of public confusion and anxiety over gene patenting. It began in March of this year, with misreading of a joint statement by President Clinton and Prime Minister Tony Blair of Great Britain. And it has been exacerbated by widespread public misunderstanding of the nature of patents, compounded, sad to say, by those of us in genomics research, who too often assume that our own highly specialized understanding of the term "gene" is shared universally.

The most common public misunderstanding seems to be that patents convey ownership, rather than temporary commercial benefits to inventors. Many laymen also seem to regard genes as an almost spiritual collective essence of humanity and therefore not appropriately subject to commerce. But the patents that my company, Human Genome Sciences, and other leading biotechnology companies have been filing are neither unusual nor threatening to our core cultural or spiritual values. The "genes" being patented are not the genes in people's bodies, much less the aggregation of all genes. Rather, "genes," as we in genomics understand them, are isolated DNA sequences and the proteins expressed by those DNA sequences—individual genes removed from the natural context of the human body and rendered useful by crafting them in specific ways for medical use. These genes are artifacts made by the hand of man, and as such, they are subject to patents. Indeed, recombinant proteins and the DNA that encodes them have been patented in numerous instances during the last 20 years.

Patents are necessary for us to reap the coming harvest of genetic treatments for ill and aging populations.



Finally, while Messrs. Clinton and Blair early this year called for free sharing of information on the human genome, their statement also specifically underscored the necessity to protect the intellectual rights to genomics-derived products and treatments. The U.S. Patent and Trademark Office has further clarified the gene patenting process by developing new guidelines that will help specify which gene-based inventions are patentable.

Under these guidelines, there remains little doubt that a full-length human gene coupled with medical utility is a patentable invention. Conversely, there is little controversy that raw genomic data with no further explanation of its utility or use is not patentable. What the new guidelines do is determine more precisely just where to draw the line between these two extremes.

Because each patent application is different, no fixed bright line can be drawn. Rather, the effort to define patentability is an administrative process that has been ongoing over the last several years and will continue in the future—both in the Patent Office and in the federal court system. And, as the numerous issued patents on gene-based inventions demonstrate, it is a process that works. ◊

William A. Haseltine is chairman and chief executive officer of Human Genome Sciences.

The raw data of the human genome should be an "IP-free zone," opines author Seth Shulman, to preserve our precious shared genetic heritage and update outmoded notions of intellectual property.

Toward Sharing the Genome

WHO OWNS THE HUMAN GENOME? A PROfound confusion reigns today over the issue of proprietary rights to human genes, and it is setting the stage for a long-term intellectual-property disaster. The U.S. Patent and Trademark Office, backlogged with tens of thousands of private claims to genetic information, cannot seem to decide where to draw the line on ownership rights; animosity between government-funded genome researchers and their industry counterparts continues to mount; and an ominous tangle of lawsuits already looms on the horizon.

And this, as everyone in the field will tell you, is only the beginning of many decades of fast-paced genomic research.

The controversy was simmering just behind the happy façade presented during the White House ceremony in June when President Clinton announced the completion of two working drafts of a human genome map. Despite the grand announcement, there is a startling uncertainty about how to apportion the lucrative information the map contains. For an economic indication of this uncertainty, look no further than the joint statement Clinton and British Prime Minister Tony Blair issued last March. In the statement, Clinton and Blair did nothing more than affirm the widely agreed-upon

BY SETH SHULMAN

ILLUSTRATIONS BY BRIAN CAIRNS


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need to maintain open access to the human genome's raw genetic sequences. Then they watched dumbfounded as a stunning flight of capital bled billions of dollars from the biotech companies involved in the genome field. Some firms, such as Palo Alto, Calif.-based Incyte Genomics, lost nearly one-third of their stock market value in one day.

The irony in Wall Street's jittery response is that firms like Incyte, Millennium Pharmaceuticals, Celera Genomics and Human Genome Sciences—the most vociferous proponents of proprietary rights over human genes—all clamored to explain that they welcomed the Clinton-Blair announcement. Why? Because these companies recognize that some level of open access to the human genome is essential to building a robust industry in the future.

These genomics firms see the tremendous potential of the decoded human genome to medical science. They know, in more detail than most of us, that the diagnostic screening tests and drugs now coming to market offer only a glimmer of the promise ahead. They also understand something else: They have the most to lose if they are shut out from developing these treatments by their competitors' capricious and overly broad intellectual-property claims.

The race to discover and patent human genes is frequently likened to a gold rush, an analogy that captures much of the current frontier flavor. But the savviest players recognize a fundamental difference. Prospectors forever removed the gold when they panned it from rivers and mined it from the earth. But the information in the human genome is not depleted upon its discovery. The genome is a resource to which biomedical researchers will return again and again to solve the puzzles of human disease; it is a wellspring that will nurture a myriad of overlapping discoveries and inventions for many decades to come. In this sense, the human genome can—and must—support what economists call nonrival consumption: a situation where multiple parties profitably share the same resource.

The problem with the gold rush analogy, then, is that the land claims that helped tame the prospectors' free-for-all were a crude but necessary framework to divide rights to a tangible and decidedly finite resource. By carving up the genome into parcels of exclusive, private real estate, the Patent Office is needlessly replaying this history. Instead, what is called for is an enlightened policy designed to govern the multiple and overlapping uses of the "genome commons": a policy that insures unfettered access to the data and materials that will serve as the building blocks for countless drugs and treatments in the future.

Although the term "commons" traditionally refers to shared property such as a city plaza or communal pastureland, the notion also applies to shared knowledge resources. We would do well to remember the 1799 discovery of the Rosetta stone, the remarkable tablet that offered the same long passage of text sequentially in three ancient languages. The Rosetta stone provided linguists over many ensuing years the seminal key to finally unlock the previously undecipherable hieroglyphics of ancient Egypt. Imagine if someone had proposed to chop the stone tablet into separate proprietary chunks. Such a plan would clearly have diminished, if not destroyed, the central value of the resource.

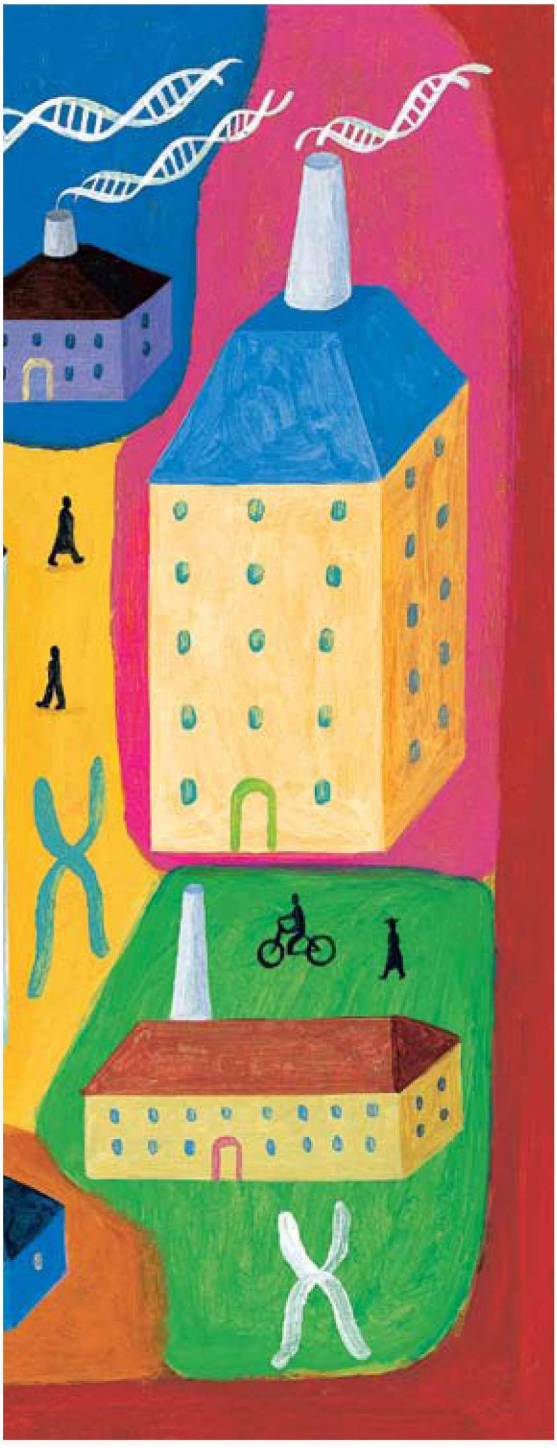
Sadly though, that is exactly what is happening now with the human genome. Companies must think about their financial bottom line. For today's crop of genomics firms, especially given the absence of clear rules, this means obtaining patents—as many as possible and with the broadest possible claims. The tens of thousands of human gene-related patents pending have polarized an already divisive situation. On the one hand, companies investing millions of research dollars argue that they need to protect their intellectual property. Without patents, they say, the private sector won't ante up the billions of dollars needed to stimulate the rapid development of genome-based healthcare products. On the other hand, the patenting frenzy is kindling understandable fears that only a few corporations will end up controlling a resource of priceless value to humanity. Some, like biologist Jonathan King at MIT, who is circulating a petition to this effect, believe the answer is to prohibit patents on genes.

Between these views is a gray area as big as the Pacific Ocean. As University of Michigan legal scholars Michael Heller and Rebecca Eisenberg explain it, the key



question is how far "upstream" or "downstream" proprietary rights ought to be allowed along the path to product development. The problem is that almost any piece of the genome can be seen to have some commercial value. But issuing patents too far upstream could leave the path to drug development looking like a pockmarked road with a nightmare of tollbooths and barricades.

While the specifics can admittedly be confusing, at root there is nothing particularly complicated about the debate



over patenting and the human genome. The key is to treat this as a vital public policy issue rather than a strictly legal or scientific one. The first thing to remember is that the human genome is a precious inheritance of the human species. For this reason alone, it deserves special treatment. Second, the project to decode the human genome has, for more than a decade, been the mission of a publicly funded project that will ultimately cost some $3 billion. Given this outlay of funds by taxpayers, the public has every right to demand that the genome is used wisely and not simply handed over for private gain. And finally, we must recognize that—with the recent, momentous milestone of a completed working draft of the human genome—the time to act is now. We can save ourselves a lot of bitter litigation, money and acrimony (and speed the next generation of drugs and treatments to market) if we adopt policies that balance the powerful drive of commercial interests with the public interest.

Here are five steps to take immediately:

1. Create the World's First "IP-Free Zone"

THE PUBLICLY FUNDED HUMAN GENOME Project began in 1988 as a grand scientific undertaking to decode all human genes and create a shared resource of knowledge that will be the foundation of 21st-century medicine. It's time to codify that status in law by creating the world's first intellectual-property sanctuary, or "IP-free zone." Specifically, the U.S. government should mandate that the genome's raw sequence data cannot be privately owned.

In a practical sense, we are already well on our way to this goal. Over the past several years, the Human Genome Project's network of laboratories have published on the GenBank Web site (www.ncbi.nlm.nih.gov/Genbank/) a steady stream of decoded nucleotide base pairs within 24 hours of sequencing them. The policy insures that the genome data will be freely available to researchers around the world, and also discourages secrecy or proprietary claims over this valuable raw data.

With the Human Genome Project's laudable commitment to open publication (thereby *de facto* disqualifying the raw data from patent claims), why bother writing a law? Because the formal establishment of an IP-free zone—a kind of "national park" of genome knowledge—will set a vital precedent that some kinds of precious information resources must be off-limits for private ownership.

As many are coming to realize as we move headlong into the knowledge-based economy, things work best when seminal information assets—particularly those needed by all players in a given high-tech sector to compete—are pooled and shared. This is the idea behind both open-source software and the hardware standards that have come to predominate in many high-tech sectors. These pieces of "infostructure" are what allow different engineers to design distinct machines that all plug into a single type of wall socket or send standardized software files over the Internet. Like public lands or public libraries, pooled knowledge assets must be made freely available and protected within a framework that preserves their integrity. Precisely because the raw sequence of the human genome—the actual string of DNA base pairs themselves—is already widely perceived as deserving of this special status as a category of knowledge, it makes an ideal candidate for the world's first legally mandated IP-free zone.

2. Declare a Moratorium on Gene Patenting

THE U.S. PATENT AND TRADEMARK OFFICE has clearly bungled the issue of gene patenting by years of equivocation and delay. We need a moratorium on gene patenting until we can all agree on sensible rules.

Patents have always represented a compact between an inventor and the public: The inventor gets a 20-year monopoly in order for the public to quickly get the benefit of the new innovation in the marketplace. Issuing broad patents that confer no such clear benefits can, as the Supreme Court noted in the key 1966 case *Brenner v. Manson,* create a "monopoly of knowledge…[that] may confer power to block off whole areas of scientific development, without compensating benefit to the public."

The most urgent task is to clarify that before a gene can be patented, it must be shown capable of providing a benefit to the public—namely by bringing a new product or invention to the marketplace. Within our legal framework, this principle is defined as a patent's "utility."

In a hopeful sign, the director of the Patent Office, Q. Todd Dickinson, has proposed to raise the "utility" bar slightly by adding three words to its guidelines. To win a patent in the human genome field, applicants will have to describe a "substantial, specific and credible" use for their gene. While this represents an



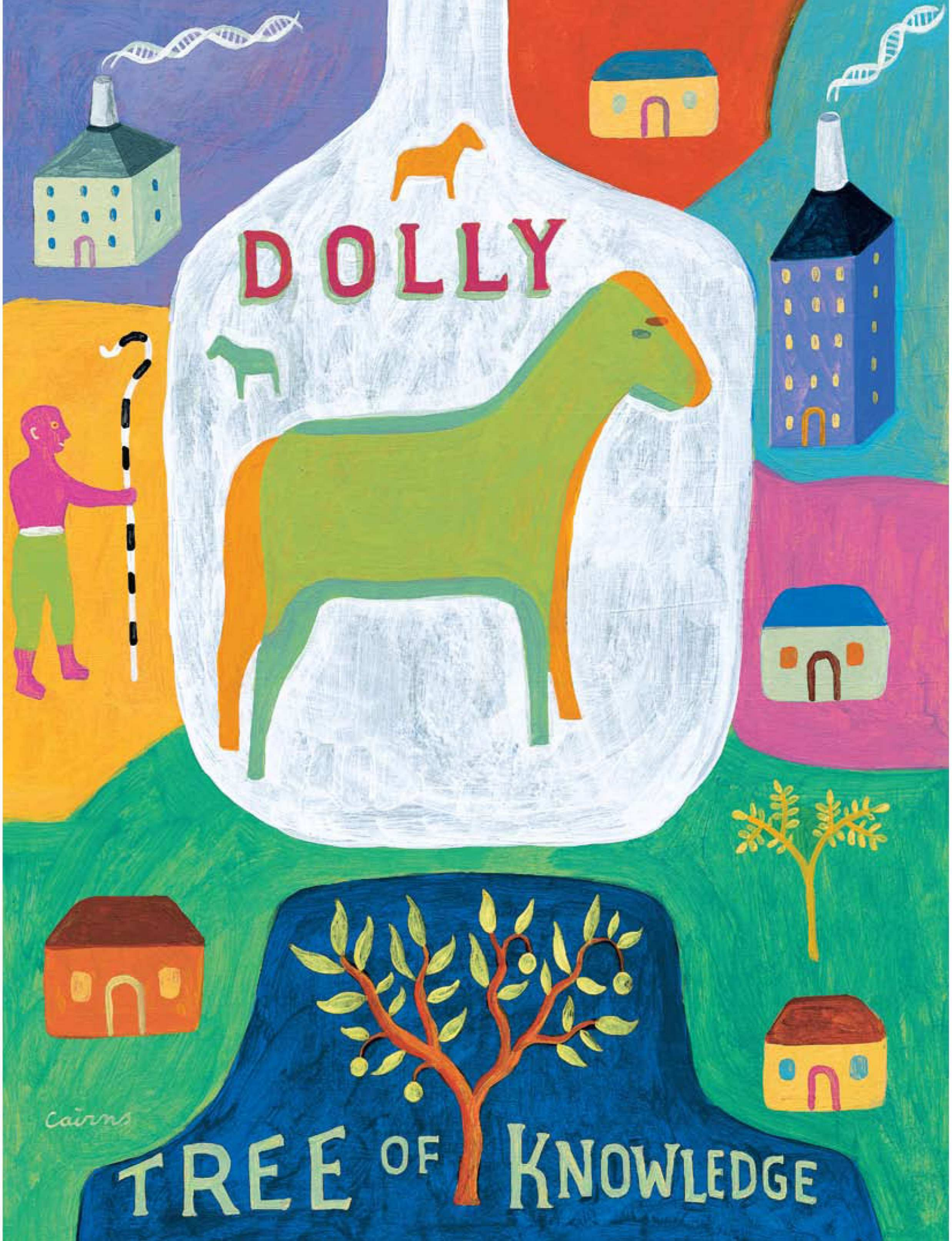
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important step in the right direction, the Patent Office can and should do more. Although Dickinson may rightly argue that his is not a policymaking body, the Patent Office's role on the front lines requires it to spot emerging problems and report them to Congress or otherwise work to redress them. To stem the continuing confusion in this area, Dickinson needs to take the lead, holding hearings that include all stakeholders and declaring a moratorium on gene patenting until acceptable rules are reached.

3. Institute a Licensing System

THE MOST TROUBLING ASPECT OF THE current spate of gene patenting is the risks that the right afforded by patents "to exclude others" poses to medicine. To avoid the worst potential problems, we need a compulsory licensing system, and Congress should hold hearings as soon as possible to figure out how it should be implemented.

Changing licensing rules would go far to insure that in the future researchers will be guaranteed the right not just to view the genome but also to use the information it contains to develop vital products. Under a compulsory licensing plan, patent holders could still receive compensation, but would no longer retain the right to exclude others from research that could improve public health. Congress needs to spell out new rules in this regard, specifying guidelines for licensing fees and perhaps adopting a sliding scale of payments for public sector vs. commercial research.

Without new licensing rules we risk replaying the sorry history of antitrust actions and patent tangles. A century ago, broad patents tied both the automotive and aviation industries in knots during their first decades. The costly and debilitating tangle of lawsuits only ended with the creation of so-called patent pools that cross-licensed everything and divvied up the royalties. The patent pools—later used in the semiconductor industry—can successfully end the worst of the wrangling. But they also tend to consolidate entrenched oligopolies and present stiff barriers to entry in the field.

If at all possible, in the case of the human genome we need to try to avoid acrimonious after-the-fact kinds of settlements. A new, transparent licensing system will help companies navigate what's likely to be an unusually complex terrain of patent claims and ensure they have access to what they need to create new drugs.

4. Establish a Zoning Commission

THE MANAGEMENT OF THE HUMAN GENOME is a vital matter of public policy. It is not something that should be left to powerful business players, lawyers or scientists to resolve alone. We need a body made up of stakeholders from the public and private sectors, scientists and laypeople alike, to serve as a kind of genomic zoning board.

In the first decade of recombinant DNA research, the National Institutes of Health (NIH) established a body called the Recombinant DNA Advisory Committee (known as "the Rack") to determine policy about what safeguards were needed for certain kinds of previously untried recombinant DNA research. Although the practice of gene patenting also presents many unknowns, there has been little analysis of its economic, social or scientific impact. There isn't even an official body within the NIH to deal with the issue. It is naive to think that a *laissez-faire* policy can be effective. We badly need a standard-setting group that can help shape policy in this emerging area.

The management of the human genome should not be left to powerful business players, lawyers or scientists to resolve alone.

Why think of it as a "zoning board?" Because zoning regulations represent a good example of how community standards can be established and enforced to shape the rules governing private property. We would do well to remember the lesson of Central Park in New York City. At the time it was proposed, the idea of setting aside 700 acres of prime real estate in one of the world's most vibrant cities was controversial to say the least. The land seemed too valuable to turn into a park, but time has shown that, for most Manhattan residents, the value of Central Park far exceeds the monetary worth of the property.

Just as zoning can add value to a community by balancing the needs of the private and public sectors, we need a public policy body tasked with balancing and nurturing the partnerships between the private and public sectors that have brought us to this stage in our understanding of the human genome.

5. Put Public Health First

ULTIMATELY, THE MOST IMPORTANT THING is to remember the overriding public health mission of human genome research—public or private. While it is tempting to try to speed development with patent incentives to private firms and universities, the impulse must be balanced against longer-term concerns for how the ownership rights to genes will ultimately affect the equitable dissemination of health-related products.

The human genome is already raising vexing policy questions about our rights to confidentiality for our genetic health information and protection against genetic discrimination by insurance companies and in the workplace. Just like gene patenting, these kinds of emerging issues will require new solutions and proactive public policy. The time to start is now. As we begin the process of balancing commercial interests and public health, we need to be guided by our sense of fairness, by our democratic values and by established methods of transparency and reporting that will insure our ability to publicly regulate the situation in the future.

President Clinton's joint announcement with Prime Minister Blair in March barely scraped the surface of the vital issue of ownership of the genome and unfortunately did little to stem the continuing uncertainty in the field. But, rhetorically at least, Clinton got it right when he called upon us to "ensure the profits of human genome research are measured not in dollars but in the betterment of human life." ◊

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BY DAVID H. FREEDMAN

Fierce competition, radical expansion, a problematic funding model and maybe a new director spell the end of an era. Can a trailblazing enterprise survive and thrive?

The Media Lab at a Crossroads

PHOTOGRAPHS BY STEPHEN SHEFFIELD AND BARRY LEWIS

LIFT THE STOPPER FROM ONE OF THE THREE ANTIQUE-STYLE COLORED glass bottles and hear a jazz ensemble riff spill out, as if the music had been freed, genie-style. Across the room, touch any of a dozen doughnut-sized plastic bubbles to see a ripple of light spread through the crowd like a rumor. Downstairs, stick your personal mug underneath the coffee machine spigot and hear your favorite station lock in on the attached radio.

Are we having fun yet? If not, there's plenty more to amuse here at the MIT Media Lab, including festive holograms, dancing microrobots and computerized jean jackets. Even better, all of these gizmos demonstrate unique approaches to technology that, the lab's faculty assert, will eventually be widely embedded in the world around us.

No wonder the Media Lab has long stood out as the high-tech research darling of the public; it's just so damned, well, mediagenic. More important, it's also the fair-haired child of industry, which sometimes literally lines up to witness the alleged future aborning and then hurls money at the lab—enough funds to allow the construction of a second building nearly twice the size of its current headquarters on the MIT campus, as well as a daughter facility in Ireland.



Nicholas Negroponte: A reduced role as the lab's "foreign minister."

But while outwardly the lab seems to be sailing along as smoothly as ever in its 15th official year of existence, in fact it now faces a series of daunting challenges that could, by the faculty's own reckoning, lead either to its attaining a vastly greater level of influence or to the enterprise's dissolution. Among these challenges are a rapid expansion that threatens the lab's renegade, collaborative culture; a management vacuum left by the shrinking role of founding director Nicholas Negroponte; the lack of a clear direction for its research; and a funding model that looks increasingly anemic and restrictive in an age in which almost anyone with a bright Internet-related idea can collect venture capital millions. "We're obsolete," says lab professor Neil Gershenfeld. "We seriously talked about shutting down. The feeling was we should either grow or shrink drastically."

The choice, made after months of debate among Media Lab faculty and administrators and just now unfolding, has been to embark on a risky strategy for growth—not only by expanding the lab, but by seeking new relationships with industry that could make the enterprise look as much like a management consulting and VC firm as a university research facility. "We've changed before, but this is different," says associate director Andrew Lippman. "In the past it was about new directions and details. Now we're talking about a change in vision."

A Bold Experiment Runs Its Course

FOUNDED IN 1985 BY FORMER MIT PRESIDENT JEROME WIESNER and then-architecture professor Negroponte, the Media Lab's mission was ostensibly to explore the convergence of various media, a bold concept at the time. But that justification was, in a sense, a cover story: From the beginning, the lab was itself an experiment in a new way to run a university-based research organization. The key to understanding this approach, points out lab academic head Alex "Sandy" Pentland, is to recognize the tradition on which Negroponte and Wiesner were drawing—namely, that of the architect guild rather than that of a science department. Instead of learning primarily from lectures and books, students would learn more from doing; instead of paying or having to teach classes, students would be paid for producing original work; and as for faculty, instead of being judged for the papers they published, they would be valued according to the public impact of their groups' projects. What's more, the approach would be decidedly multidisciplinary. "Universities have iron walls around disciplines," says Pentland. "In the guild, it was what you produced that mattered, not what went into it."

The other part of the experiment was the Media Lab's sponsorship model—really more a form of patronage. Negroponte made corporations this offer: Give his operation a chunk of money and gain access not merely to one research project, but to all research within its confines. Sponsors would be welcome to rub shoulders with faculty and students, ask questions, make suggestions and absorb the creative energy brimming inside. The downside was that sponsors wouldn't get to specify or influence any of the research or obtain any unique rights to it, as they typically might in funding university research.

This might seem a pretty skimpy payback from the corporate point of view. But Negroponte proved remarkably adept at selling the proposition, bolstered by the growing perception that something magical was happening—the result of brilliant public relations and a flattering popular book by Stewart Brand called *The Media Lab: Inventing the Future at MIT*. "You could say we engineered the good press," says Negroponte. "But the simple fact is that the media likes to write about the media." In any case, money has not been a problem; the effort now counts some 175 sponsors who provide $33 million of the lab's roughly $35 million annual budget (the rest comes from MIT and a few government projects). Individual sponsors typically ante up $200,000 a year, but some chip in more. Mastercard, Motorola and Lego, for example, have given $5 million each to the lab in exchange for closer-than-the-usual collaboration with certain research groups.

"Doing anything that jeopardizes the cross-connections would be crazy. Finding that balance will be a problem." —MITCHEL RESNICK

Of course, the lab has long been the subject of grumbling from rivals inside and outside of MIT. These critics charge that the place gets an awful lot of attention just for churning out cute, flashy toys that—unlike the outputs of, say, MIT's esteemed but less glamorous Artificial Intelligence Laboratory and Laboratory for Computer Science—almost never break technological ground, prove significant scientific theories or end up as important products. "We all recognize and envy the high profile the Media Lab has," says John Anderson, a professor at Carnegie Mellon's Human-Computer Interaction Institute. "We also recognize that some of the work is kind of questionable."

But though Negroponte's creation tends to be perceived as a practitioner of research as an extreme sport, it is neither the exotic, future-inventing wonderland that is packaged to the public nor the tired repository of third-rate science-cum-eye-candy pilloried by its detractors. In fact, hype and resentment aside, the lab has carved out a fertile, if not as of yet terribly impactful, research niche for itself at the interface of computer technology, soft science and the arts—and the results could have at least an indirect influence on generations of products to come. "Computer science departments have people who are strong at figuring out how to make things, but you don't see people looking at what these things mean and how you apply them," says Ken Perlin, director of New York University's Media Research Laboratory. "The Media Lab has broadened the definition of science to put together the science of things with the science of what people want, and that's gutsier."

That the Media Lab continues to be other than your typical academic department becomes quickly apparent in a tour of the building, which itself has the feel of a very large, colorful, high-tech toy. Mannequins, musical instruments, rubber chickens and rivers of wires are strewn throughout the glass-walled, mutedly lit workspaces. In addition to these inanimate obstacles, one also has to squeeze by an apparently never-ending international stream of journalists, camera crews, sponsor reps and visiting academics—not to mention students sprawled on the floor soldering or huddled around a computer screen in an act of communal debugging.

Although the energy is evident, the nature of the domain



Mitchel Resnick: Lego legend will help construct a new center—but foresees problems.

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Tod Machover: In the Dublin lab, orchestrating the Media Lab's expansion.

LEWIS

into which it is being poured has become increasingly unclear. Ask a dozen different professors what business the Media Lab is in, and you get a dozen different answers. "It's about 'me, means and meaning,'" pronounces Gershenfeld, who says he's referring to the study of people, of embedding technology in everyday objects and of the content associated with these efforts. Walter Bender, who runs two large publishing-related research groups, insists that the lab studies "learning through expression." Still others suggest the endeavor explores ways to weave technology more seamlessly into people's lives.

This lack of a clear theme results in an almost scattershot feel to the research that takes place inside—as if the place isn't so much inventing the future as making a run at interesting slivers of it. Consider, for example, the colored, stoppered bottles that "contain" music. These come from Hiroshi Ishii's "Tangible Media" group, which explores how information can be transmitted and controlled by tactile means. The bottles are typical of many projects in that, at first glance, they come off as engaging and trivial, but after a little explanation the ideas behind them seem plausibly significant. "Current technology impoverishes the human senses," explains Ishii. "If you have to manipulate objects with your hands, then visual information might not be the best form of feedback."

"Five years ago you could hold a meeting that included everybody. Now I don't even know everyone in the building. It's too late to go back."

—Tod Machover

Rosalind Picard's "Affective Computing" group, meanwhile, strives to get computer-controlled devices to recognize tip-offs to a user's feelings; a wireless voodoo doll that a desktop computer user is encouraged to hurl against the wall, for example, can keep track of which computer annoyances preceded the launching so that they can be identified and fixed. Lippman's "Digital Life" group has looked at real-time variable supermarket pricing, so that the price of a container of milk could drop as it approaches its shelf date and specials could be tailored to a shopper's preferences. Tod Machover's performing arts contingent produces instruments that allow people with no musical training to create rich sounds. And the lab recently snatched up young Stanford physicist Scott Manalis to work on ways of integrating semiconductors and biological materials, perhaps resulting in chips that can be implanted in the body to monitor health.

It's not easy to come up with a conceptual umbrella that covers this far-ranging activity. When asked how Manalis' work fits into the lab's research theme, Lippman ponders a long moment, then shrugs, "I don't care." Says Pentland, who works on wearable computers, among other things: "Maybe there isn't a tight definition of what we do here. But there isn't a tight definition of physics, either." Pattie Maes, an expert in intelligent software agents, suggests that the lack of any clear theme is in fact the lab's theme. "Most labs are getting better at a narrower and narrower domain of expertise," she says. "We try to be different."

The question of theme might not matter if it weren't for the radical upheaval that the lab is about to undergo as it doubles in size over the next two years and expands into an attached new building, an orgy of clear glass and metal rods scheduled for occupancy in 2003. "Our biggest problem is being fresh again," explains Picard. "With a PC and the Internet, the average 16-year-old can be as innovative as we are." She and others agree that the enterprise will require more than a bigger play space to fend off diminished relevance in an era in which significant technological change occurs almost monthly, and more and more people and institutions are treading on its turf. It will also need a different model for managing itself, since Negroponte's family-style approach to making big decisions has already fallen victim to sheer mass. "Five years ago you could hold a meeting that included everybody," says Machover. "Now I don't even know everyone in the building. It's too late to go back."

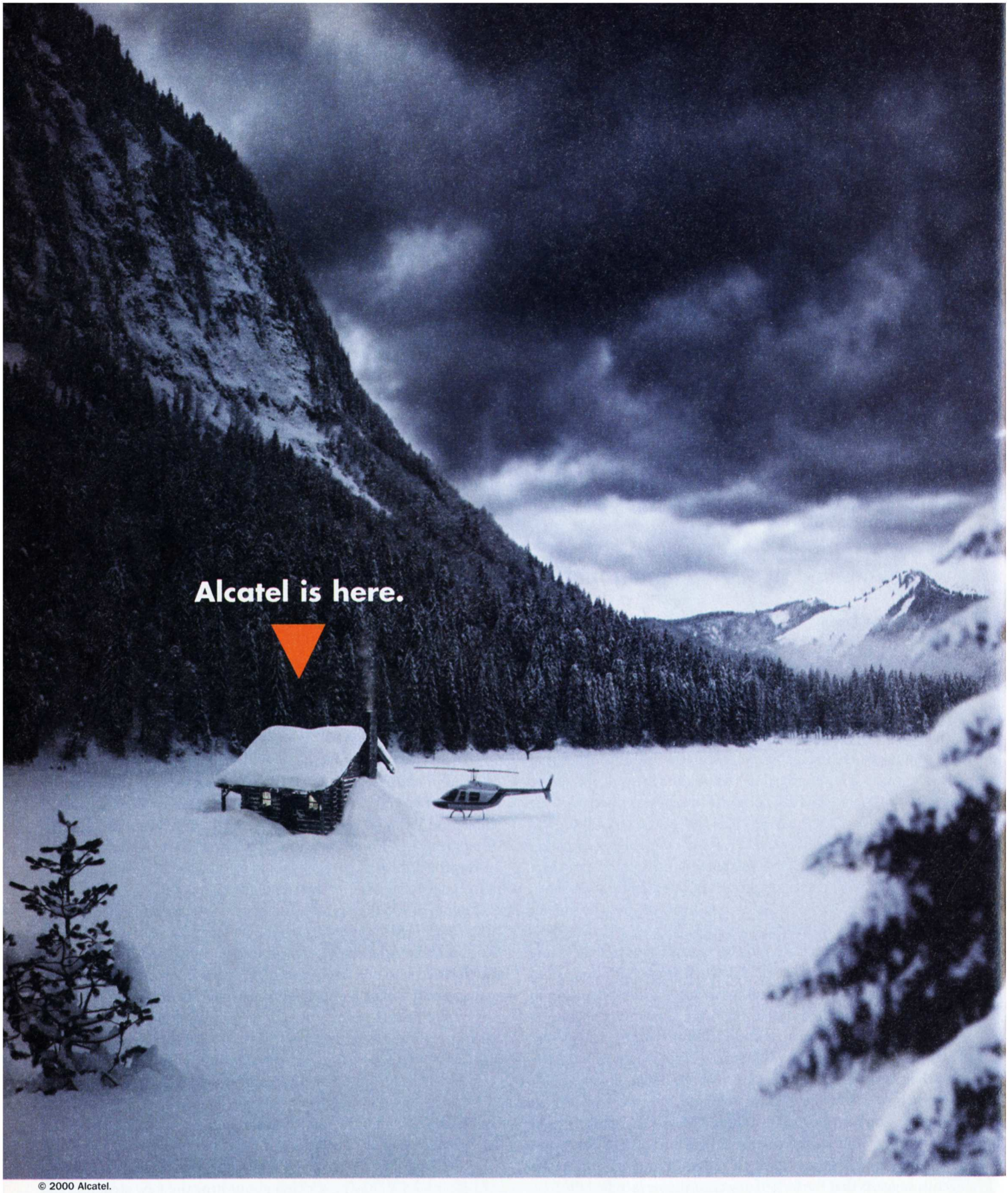
The Media Laboratories

THE SOLUTION, TO BE IMPLEMENTED BY THE TIME THE LAB TAKES over its new building, is to divide the facility into three distinct and largely independent "centers," each of which will be a Media Lab in its own right; the endeavor as a whole will pluralize its name to become the MIT Media Laboratories. One center, under the direction of Mitchel Resnick and already funded with a $27 million grant from Sega Enterprises chairman Isao Okawa, will be dedicated to education and Third-World development. A second, run by Gershenfeld, will focus on what the lab cloyingly calls "bits and atoms"—meaning how physical objects can be imbued with electronic intelligence. The theme of the third will be performance and the arts, to be "conducted" by Machover.

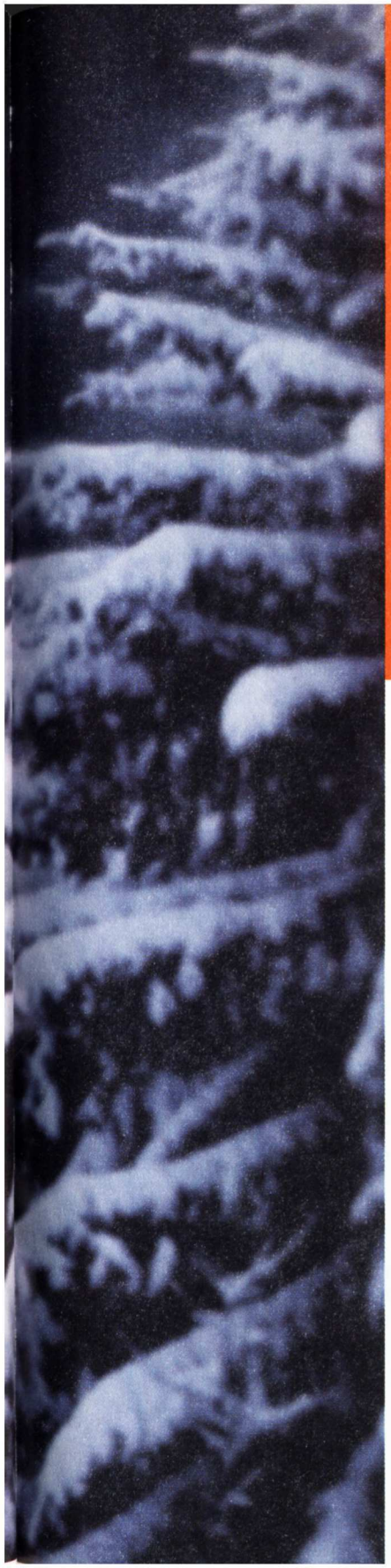
These choices have not been without controversy at the lab, especially among senior faculty. Bender, for example, argues for a simpler twofold structure based on the themes "Things that think" and "How do people use things that think?" Pentland and others lean toward adding a fourth center, though there's no agreement as to what its focus should be. The real problem is that many faculty members—among them mainstays like Lippman and Bender—don't see their work fitting comfortably into any of the three centers, even though the centers themselves are multidisciplinary. Apparently, some are even concerned that being shoehorned into one could mean being placed under a layer of management that won't necessarily view their work as a high priority. (As this article was going to press, the lab was preparing for a summer retreat at which such issues were to be addressed.)

Gershenfeld somehow manages to sound both empathetic and cold-blooded about the queasiness with the tri-lab structure. "There's a great deal of concern over the issue of people who feel they don't fit in," he says. "In some sense, it's correct—they don't, not anymore. There's a certain amount of legacy here."

Even some faculty members who aren't fretting about fitting into a center say they're worried about how the new structure will affect the lab's unusually collaborative culture. Resnick, though he will be running one of the centers, shares that fear. "There's a clear advantage to having clusters with intellectual coherence," he says. "At the same time, doing anything that jeopardizes the cross-connections would be crazy. Finding that balance will be



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a problem." So far, the only solutions proposed for keeping those connections alive are to maintain some common areas and to hold occasional shared events. Both Lippman and Bender say they fear that even if the centers succeed individually, they will leave the overall lab weakened.

Negroponte has by all accounts proven masterful at maintaining a sense of unity and mission among his charges—not to mention the lab's sterling reputation among corporate leaders and the public worldwide. Although only 56, he plans to pull back from his management role, even as his brainchild enters what some feel is the most vulnerable period since its founding. Negroponte downplays the effect his reduced commitment will have, claiming he has long since faded from the front lines. "The lab is often identified as Nick's Lab," he says, "but these days I often sit in the back of the room. I'm more like a foreign minister, tooting the ML's horn." And it's true that in an interview, he looks like a visitor in his own large, mostly bare corner office, which is routinely used as a faculty meeting room.

The lab isn't discussing what it might do to replace Negroponte—nor would anyone indicate when any replacement might be made. But Gershenfeld says an executive board of "heavy hitters" will likely be formed to share decision-making powers with whoever becomes director. One person cited as a board candidate is John Seely Brown, just-retired director of Xerox's Palo Alto Research Center. Brown won't say whether he'd consider such an offer—but he sounds upbeat on the topic, noting that extensive conversations with key players have convinced him great things are afoot. "I've become an extremely strong supporter of this style of research," he says. "I had lots of questions before, but now I'm more and more impressed with the direction of the lab." Another heavyweight already in the lab's camp is 3Com co-founder and *TR* board member Robert Metcalfe, who recently joined the Irish venture's board.

"We seriously talked about shutting down. The feeling was we should either grow, or shrink drastically." —Neil Gershenfeld

However things are run, management will almost certainly face a rethinking of the venerable sponsorship model, which has been a source of the lab's strengths as well as of many problems it now faces. Sponsorships have in effect served as collective MacArthur grants that have allowed research groups to follow their intellectual fancy. Because faculty members generally don't have to impress peer-review grant panels, there is reduced pressure to publish in academic journals, though many do. (Tenure, says Negroponte, is awarded on the basis of "becoming famous in your field"—which can be less daunting than it sounds, since lab faculty members typically operate in tiny fields they founded themselves.)

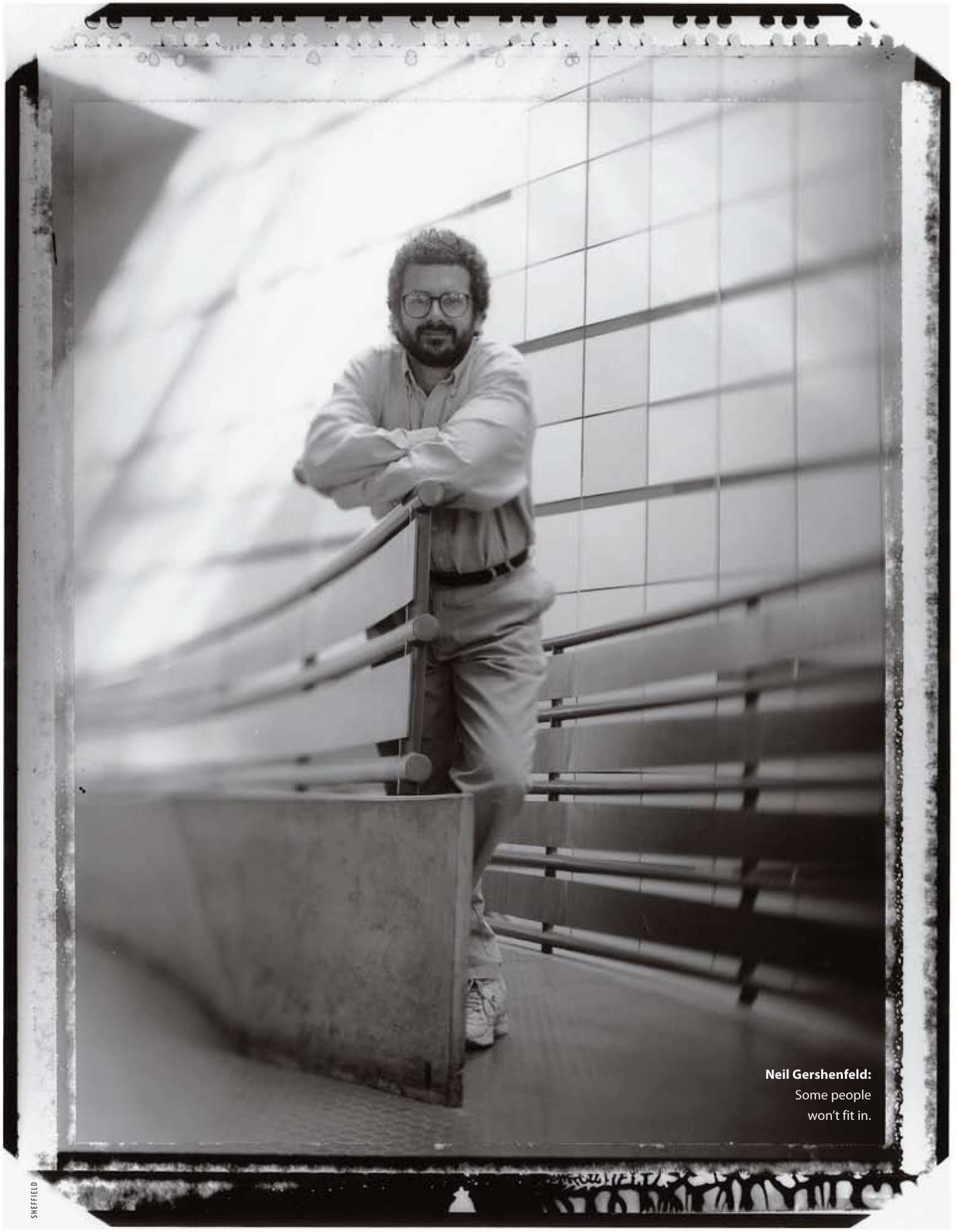
In return for such unconditional support, faculty give backers personal attention—usually via students, who average two or three meetings a week with sponsors and ultimately become polished demo-givers. But because sponsors can only ask questions, and not pressure researchers to follow up on them, rarely does anything tangible seem to come out of the interchanges. Staffers claim that products do sometimes emerge from their efforts, but everyone offers the same two examples—an NEC airbag system that prevents deployment if the body-position sensors pioneered in the lab detect the presence of small children, and the Lego Mindstorm programmable "brick," a direct offshoot of the computerized toys developed by Resnick's group. Indeed, most faculty members make it clear that they don't want to be working on projects that will directly lead to products. Says Picard forthrightly: "If we're turning out products, we're not innovating."

The result of all this freedom from orthodoxy is that the lab tends to turn out work that, by the faculty's own admission, doesn't follow either conventional scholarly or commercial standards. Members stress that their mission is to do work that is keenly original. But as a recent immigrant from a hard-science lab, Manalis can't help noticing that there can be a fine line between the original and the goofy. "In a traditional lab you have to dig really deep, but that's not always encouraged here," he says. "It's easy to ride high and stay on the surface, and the work becomes faddish." Agrees Judith Donath, who runs the "Sociable Media" group, "Some of the work is too flaky." Another criticism that regularly pops up—typically from observers at other universities who speak only on condition of anonymity—is that the cozy relationship between the Media Lab and its sponsors gives faculty such freedom from normal pressures and oversight that it breeds a certain amount of arrogance.

But the compulsion to re-examine the sponsorship model doesn't come from these sorts of criticisms, which the lab has been shrugging off successfully for 15 years. Nor does it come from corporate reluctance to keep the money flowing. Rather, it stems from the fact that over the past five years an even more generous provider of funding has emerged: U.S. capital markets. Suddenly, the Media Lab has found itself competing with billion-dollar startups on its own turf. The VC-backed startup strategy is "a higher-octane model than ours," concedes Pentland.

Media Lab students have gone with the flow: Most used to take jobs with sponsors after graduating, but now the majority end up in a startup, often one they've founded around their work at the facility—and sometimes before finishing their degrees. Lab faculty are finding that in this new, more fluid environment, the Media Lab sponsorship arrangement actually entails *more* constraints than researchers at conventional institutions face. That's because sponsors have the rights to *everything* developed in-house—and faculty aren't supposed to take their work into their own startups or make private deals to sell it to anyone else. Students, though, aren't constrained in these ways—and faculty members sometimes sit on the boards of their students' companies. Conceivably, a professor could form a company and have it become a sponsor in order to get rights to his or her own work, but the lab made this approach less appealing by limiting faculty ownership of sponsor companies to 5 percent.

Some professors have managed to start companies related to their work anyway—most prominently Maes with Firefly, a Web comparison-shopping concern recently purchased by Microsoft, and Joe Jacobson with E Ink, which is developing new types of electronic paper that act like displays. But these spinoffs have reportedly engendered resentment within the lab and among sponsors. (Maes says she'll be leaving at the end of the coming



Neil Gershenfeld: Some people won't fit in.

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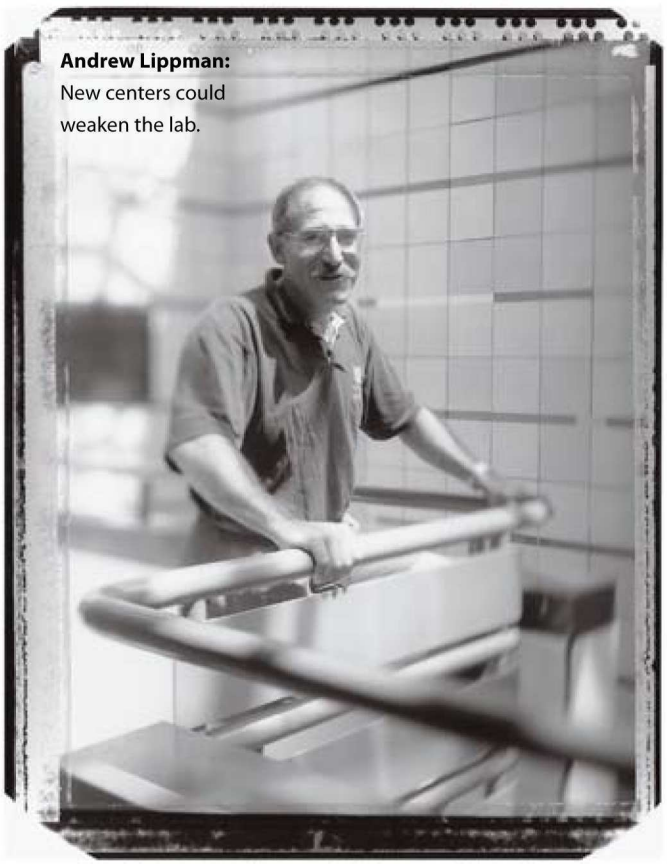
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Andrew Lippman: New centers could weaken the lab.



Sandy Pentland: Ponders "the slippery slope to hell."

SHEFFIELD

academic year, but insists her departure is amicable and motivated only by her desire to spend more time with her family and work with nonprofit organizations.)

To remain competitive in a VC-mad world, the lab appears set to reshape or augment the sponsorship model. Negroponte has held high-level meetings with MIT's provost and engineering dean *(see "Rough Sailing at the Media Lab," TR March/April 2000).* The aim, says Gershenfeld, is to win university approval for a scheme that would enable the facility to partner with other investors in startups based on its technology. Faculty wouldn't directly own equity in the resulting firms, but some of the profits from the lab's stake could flow to them—a plan he acknowledges could have dramatic effects. "The new revenue-sharing and IP [intellectual property] policies will make us look more like a company than a research lab," crows Gershenfeld.

Pentland envisions an even more radical metamorphosis. He suggests the lab might evolve into a "meta-incubator," essentially working with large companies to help them establish startups around Media Lab and other technologies, with venture capitalists and business-school partners coming aboard. "To many companies we'd look like a consultancy," he says. "That ought to be worth a couple of hundred thousand [to a corporate sponsor]." Pentland says he has had informal talks about the plan with faculty at MIT's Sloan School of Management, but adds that other universities also might be involved.

Still Taking Risks

SOME INSIDERS EXPRESS FEAR THAT ONCE THE FACULTY STARTS thinking so much about the money that could come out of their ideas, they will hesitate to share their best thinking. "The change in trust and openness could rip us apart," says Negroponte. "As soon as one person at the table isn't open, it becomes an epidemic. We keep looking for ways to fight it." Worries Pentland, "How do you manage that process without going down the slippery slope to hell?"

And what about the original mission to promulgate a novel style of academic environment? Largely ignored for years both inside and outside the lab, it is now moving to the forefront, as more and more senior faculty members start to question whether their enterprise has achieved the sort of pervasive, world-changing impact they once envisioned. The result is a plan to spread the model farther and wider by founding spinoff facilities. "This is a methodology," says Bender. "We should be able to replicate it."

The first such venture will be opening next year inside a former Guinness Brewery in the heart of Dublin. In affiliation with several as-yet-unnamed European universities—in Ireland and on the continent—the new MediaLabEurope will focus on the performing arts and media content. Latin America and Asia are being considered for a second spinoff. Besides extending the Media Lab's reach, one benefit to these offspring is they can serve as relief valves for intellectual property conflicts at the mother ship, since their sponsorship models allow for easier migration of technology to startups.

It may seem a little foolhardy to tackle these sorts of spinoffs just as the lab finds itself grappling with its ambitious headquarters expansion and associated internal conflicts. On the other hand, says Negroponte, "We've always had a license to take risks." So why put off safely for tomorrow what can be done dangerously today? ◊

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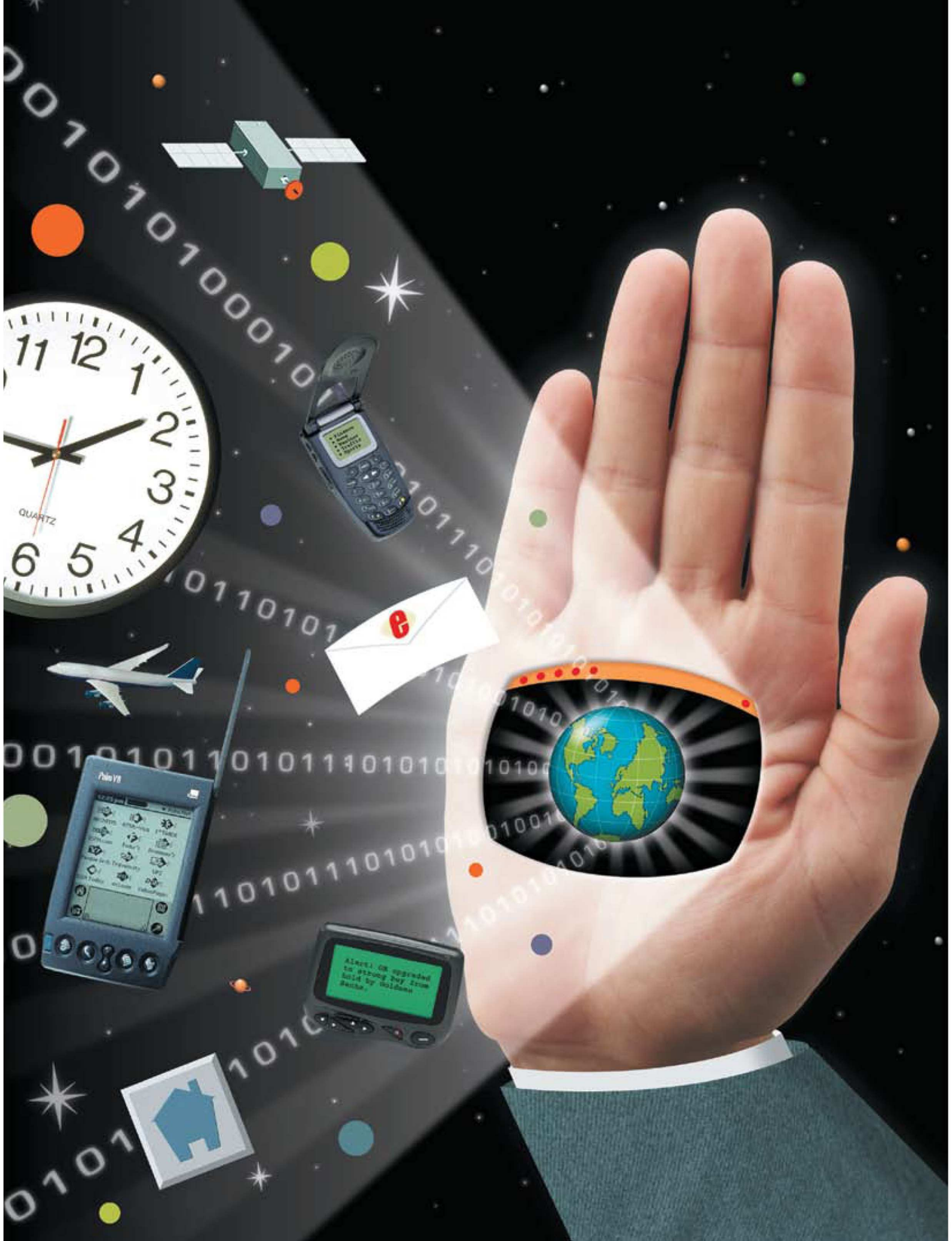
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Palm VII

Handheld devices are taking computers from personal to intimate. A new generation of wireless network is coming that could keep everyone connected all the time.

Internet Every-where

By John Adam ILLUSTRATIONS BY JOHN UELAND

AT A NEW MANUFACTURING PLANT OUTSIDE SAN DIEGO, ROUND-the-clock shifts fill pallets with wireless phones ready to ship to Sprint and other providers. The products in question are thin circuit boards destined for the next generation of handheld devices to access the Internet. Each circuit board inside this Denso International plant reveals why handhelds have become wildly popular: They blend humans and machines perhaps better than any prior invention. Analog chips, which render emotionally toned voice, share the board with digital signal-processing chips that are brilliant at manipulating data. Natural human communication and data—it's a compact and capable combination that is ready to fuel the next stage of network development: the mobile Internet.

The circuit boards rolling off the Denso line are harbingers of an explosion that may dwarf the growth of PCs. America Online took more than 10 years to reach 20 million subscribers. NTT DoCoMo, the Japanese company with the country's largest Internet portal, expects to reach that rarefied stratum in less than two years for subscribers of its mobile data service. Within several years a billion people—1 in 6 on the planet—are likely to access the Internet through portable wireless devices, according to analyst and company estimates. "They used to say every home will have a PC," says Dave Oros, CEO of wireless startup Aether Systems. "I believe every pocket will have a handheld."

This explosion is coming soon. Within two to three years, large numbers of consumers will have high-speed access to the wireless Internet. Next May, Tokyo will debut commercial operation of a so-called third-generation (3G) wireless network—one in which high-speed data capabilities are built in from the get-go. NTT DoCoMo plans to extend the multimedia network to cover all of Japan within three years. Sprint PCS says that it will introduce 3G service in the United States in late 2001; Vodafone will do the same in Britain in early 2002.

"This will smooth the rough edges of life," predicts Richard Howard, vice president for wireless research at Lucent Technologies' Bell Labs. If the immobile Internet of the 1990s seemed big, networked handhelds will be bigger: reaching more people and more machines in more countries of the world and offering novel capabilities.

Generation Hopping

GETTING A WIRELESS HANDSET to tap into the Internet takes some finagling, because just about everything on a wireless device is diminutive compared to a PC—memory, processing, power supply, keypad and screen. In addition to the problems of engineering the individual devices, there's also the vexing issue of enabling the dozens of different models to talk to each other. To attack that problem, Ericsson, Motorola, Nokia and Phone.com (formerly Unwired Planet) teamed up in 1997 to craft a new standard, called wireless applications protocol (WAP). The goal of the so-called WAP Forum was to develop a universal, open specification to bring the Web to the tiny screen. They succeeded in many ways. More than 100 companies are participating in the WAP Forum; a growing number of servers and handhelds incorporate WAP 1.1. One result, observes Yvonne Verse, a WAP Forum board member from Motorola, is that consumers can now buy any device and not worry about compatibility.

With speeds up to 2 megabits per second, the third-generation wireless networks due next year will leave today's connections in the dust.

Surfing the Web through a handheld is just the latest phase in a rapid technological development that began with analog networks, which are still common in the United States outside of congested urban markets; these are what garden-variety cellular phones use. The so-called second-generation networks now common in densely populated areas traffic in digital bits rather than analog waves. Subscribers to second-generation networks benefit by more secure conversations, better battery power management and services such as caller ID and messaging. More recently, WAP has made possible access to Web sites with a level of security adequate for many consumer transactions. The screen on the handheld that Denso is manufacturing in California, for instance, shows icons for Sprint, America Online, Amazon.com, Yahoo, Fidelity Investments and Bloomberg News. That little screen is now extremely valuable real estate.

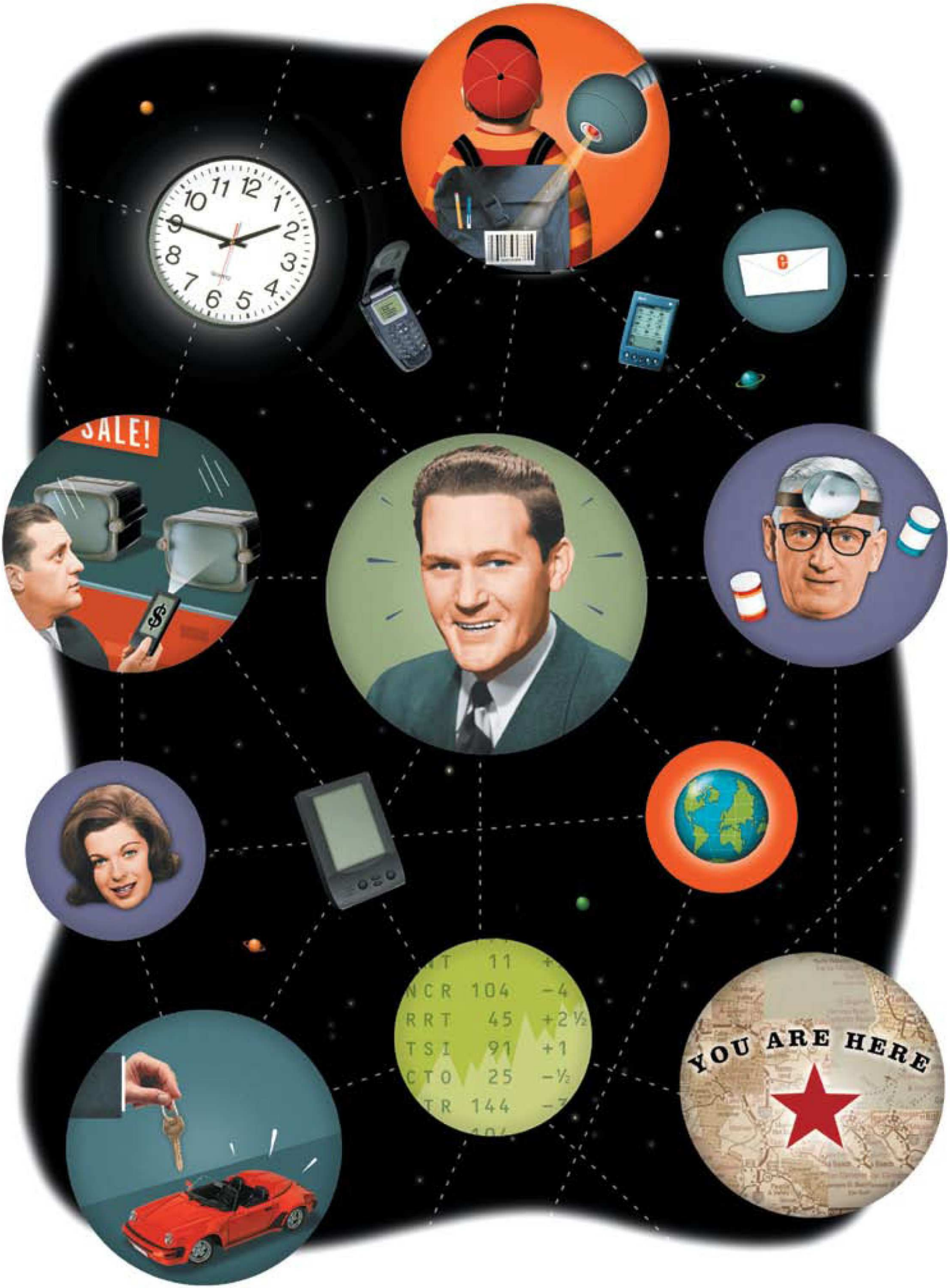
Although Web access and commercial transactions are now eminently possible on a handheld, so far the big winners from the second-generation networks have not been consumers but service providers. Indeed, the pressing reason for 2G deployment was that digital code could be transmitted more efficiently over airwaves, so carriers could serve six to eight times more talkers within a given cell. Suddenly 1,000 customers became 8,000. And Nortel Networks believes the new generation of wireless infrastructure can reduce an operator's cost dramatically—from 37 cents per megabit in 1999 to 4 cents per megabit in 2004. Data services, though, have been something of an afterthought.

Thanks to more capable electronics for handhelds, communications companies are scrambling to deploy so-called 2.5G (for generation 2.5) networks more attuned to the world of data. In earlier networks, whether analog or digital, each call creates a circuit that reserves a channel between two parties for the entire session. The 2.5G devices are the first to use Internet-style, packet-switched networks; they send bursts of data only when needed. Because these devices don't hog an entire circuit, they can be "always on."

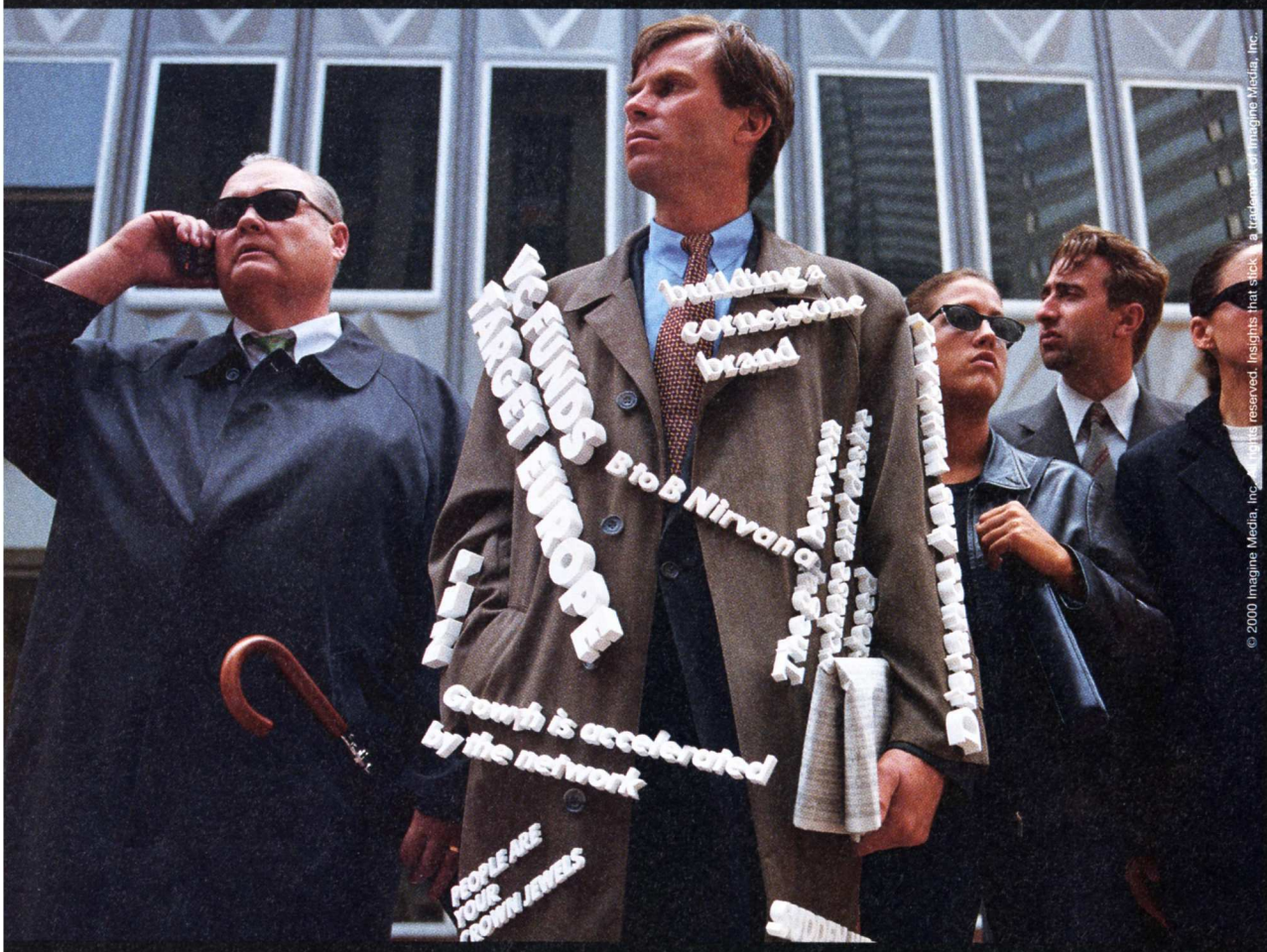
And the 3G networks coming soon will open new vistas in wireless bandwidth. Today's digital wireless handsets typically handle around 14.4 kilobits per second—the speed of home computer connections nearly 10 years ago. The 3G systems will leave that in the dust. 3G will provide 144 kilobits per second for people in moving vehicles and 384 kilobits per second for pedestrians, along with a blazing 2.2 megabits per second for fixed office environments (the faster you move the harder it is for the handheld to sort out the signal). Such speeds will allow wireless transmission of rich multimedia material. With more capable devices and networks, a user can listen to a song while she checks e-mail or bank statements. Tourists will be able to send snapshots or videos wirelessly to loved ones direct from the scene. In essence, we can all be television correspondents filing real-time reports from the field.

First, We Shop

ONE THING THAT WILL MAKE us better correspondents is the capacity of our handhelds to pinpoint our location. Indeed, the value of wireless handhelds will be greatly increased when the network can


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tell where they are. A number of different technologies are now being developed to locate wireless devices with greater accuracy *(see "Location, Location, Location," below)*, including a promising new system called Bluetooth created by Ericsson and now being exploited by a plethora of companies. Many of the early uses of Bluetooth and its location-finding counterparts will center on that universal human pastime: shopping.

As an example, the screen of a wireless device could continuously change as you walk down a street, tempting you with various offers. Your spouse's screen might differ from yours, even though you are near the same bookstore, restaurant or shopping center. When you pass a certain store, your "To Do" list stored on a network reminds you to pick up an item that has been spotted in the store's virtual database, says Lucent's Howard. Or maybe a local store—it could be a Jiffy Lube or a grocer—wants to drum up business one Thursday morning. It offers a discount for the next two hours to all receptive people within a 1-mile radius.

It's also conceivable to blend personal "buddy lists" with geographic location, so any networked friends passing within five blocks will know you are at the coffee shop, amenable to old-fashioned face-to-face conversation. No friends in the vicinity? Picture this: A Bluetooth query emanates from your handheld, finds a person with similar hobbies two tables down and makes a consensual wireless introduction.



Systems that approximate these visions are already under development. At Stanford, for instance, electrical engineering grad student James Cutler has demonstrated location-based services for a bookstore to show how digital connections might improve tactile brick-and-mortar shopping. Browsers wandering to the history section, for instance, would be presented with a Top 10 list of history books on their handheld devices and then be able to call up book reviews. To save time, they might pay electronically—maybe after being offered a discount for being a repeat customer. Walk out the door of the store and an electronic receipt is zapped into the device. "Microtransactions" might pay for a traffic report for a fraction of a cent.

An MIT Media Lab project called Impulse looks to blend the power of Internet comparison shopping with the tactile appeal of real-world stores. In one demo, during a walk through Harvard Square, a software "agent" running on a wireless mobile device finds that Wordsworth Books offers the best local price for a particular title. You click to buy the book and pick it up at the store's checkout counter. In a music store, you use the device to scan the UPC code on a CD player. You notify other virtual vendors that this is a competitive bid and disclose the desired model, a two-day required delivery, your name and your present location. Thus a store in the physical world serves as a showroom for dozens of e-merchants.

Commercial companies are starting on much of this already. Tempe, Ariz.-based IQ Order (recently acquired by Infospace of Redmond, Wash.) maintains a database of UPC codes to aid comparison shopping. Motorola, Ericsson and

Location, Location, Location

Although cyber dogma declares that the Net frees people from geographical constraint, much of daily life still takes place in reality, not cyberreality. Wireless services often work better if they know where their users are in the gritty physical world. Service providers can now locate wireless users by correlating phone numbers with particular cells. Cell sizes now vary from as small as a few blocks to as large as several square kilometers, and their size may contract as wireless traffic congestion intensifies. By October 2001, the Federal Communications Commission (FCC) will require wireless service providers to be able to locate a caller to within 50 meters. The expressed reason is safety (for enhanced 911, or E911, emergency service), but this level of accuracy opens the door for much more than improved emergency medical service.

A wireless network company can compute a user's position from the time delay between the arrival of the handset's transmitted signal at three radio towers. For a more accurate reading, the network can be supplemented by the Global Positioning System (GPS) *(see "Has GPS Lost Its Way?" TR July/August 1999)*. The GPS-assisted handset approach is offered by companies such as SnapTrack of San Jose. It offloads much of the processing work to a server that within a few seconds determines latitude, longitude and altitude to within 50 meters. SnapTrack (recently acquired by Qualcomm) claims its patented receiver can pick up GPS signals in urban canyons and inside buildings.

Location-sensitive wireless devices don't necessarily rely on a satellite network. The embryonic communications technology called Bluetooth, conceived by Ericsson, is now being developed by more than 1,000 other companies, including Intel, Microsoft, Toshiba, Motorola, Nokia and IBM. Bluetooth—named after a medieval Nordic king—creates ad hoc networks between all manner of electronic devices. The technology works not by determining universal coordinates but by simple proximity. Each carrier of a Bluetooth-enabled handheld imbues the immediate vicinity with a "hemisphere of influence" by emitting a high-frequency radio signal. Any Bluetooth machine coming within range is fair game for binary exchange, allowing the PC on your desk to synchronize data with the handheld in your pocket. Once security links are created, the data flows on its own, without human prompting.

The short-range version of Bluetooth connects devices within a 10-meter radius. It will help synchronize data between handhelds and computers, tie headsets to phones or link security cameras to the Internet. A longer-range Bluetooth would extend the links to 100 meters. All this will enable ad hoc networking for such encounters as checking into hotels, ticketing at airports or movies and searching for nearby friends. Skip Bryan, director of technology market development at Ericsson Cellular Center in Research Triangle Park, N.C., expects Bluetooth to ship in large quantities next year in phones, headsets and circuit cards that can be installed in PCs.

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Symbol Technologies recently formed a company to facilitate scanning by handhelds. A user might scan the code from a real product, a magazine page or a TV ad and launch into the virtual world for more information or comparison shopping; push a button and the device places the order. Simon Properties has outfitted shopping malls around Atlanta with bright green scanners called Fast Frogs, made by Symbol Technologies. Teenagers wandering among shops use the borrowed frogs to scan items they want to buy. The data travels through the air to an Internet-connected PC at the mall's main office so that relatives who were wondering what to buy the kids can order gifts online or at the stores.

Also on the commercial horizon are new combinations of wireless, Web and telephone. Companies such as NetSearch, recently acquired by Aether, generate leads from Web surfers who fill out forms requesting contact while researching Lexus, Toyota or Lincoln-Mercury cars. Wireless devices enable a salesperson to respond within about 20 seconds, usually while the customer is still online, says NetSearch president Gus Esposito. For corporate users, Vodafone envisions electronic invoices or contracts to be signed, issued and returned in real time while the two parties are still on the original voice call.

A Moving Experience

THE POWER OF WIRELESS CONnections goes beyond greasing the wheels of consumerism. The technology also will bring Net access to all those people who don't work at a desk with a fast, hard-wired connection. Medical professionals, teachers, business travelers and delivery workers, for instance, are starting to toss away clipboards and claim forms in favor of a wireless web of Palms, PocketPCs and WAP phones.

Dallas' Veterans Administration Medical Center is a case in point. According to a 1999 study by the Institute of Medicine, some 7,000 Americans die each year due to improper administration of medication. In an effort to avoid such mistakes, the hospital recently installed a wireless network that links handhelds carried by medical staff. Dallas VA nurse Ruth Jara says patients in the VA nursing home may be taking as many as 15 medications, often with similar-sounding names. The potential for confusion and human error is boundless. With the new system, a robot dispenses the correct dose and barcodes each medication. Nurses scan their own ID badges, the barcodes on the medication and the patient's wristband. A central computer correlates this data to ensure that the right dose of the right drug is administered and to create an audit trail.

Teachers at Smithtown High School on Long Island are using Palms and a wireless network to scan student ID cards for attendance at every class as well as processing tests and reports. Administrators get special handhelds equipped with master schedules of all students. According to Jay Landau, instructional coordinator for the town's school district, the devices let teachers spend less time on paperwork and more on instruction. The ID card of a student roaming the hall can be scanned, instantly revealing where he or she is supposed to be.

Now!

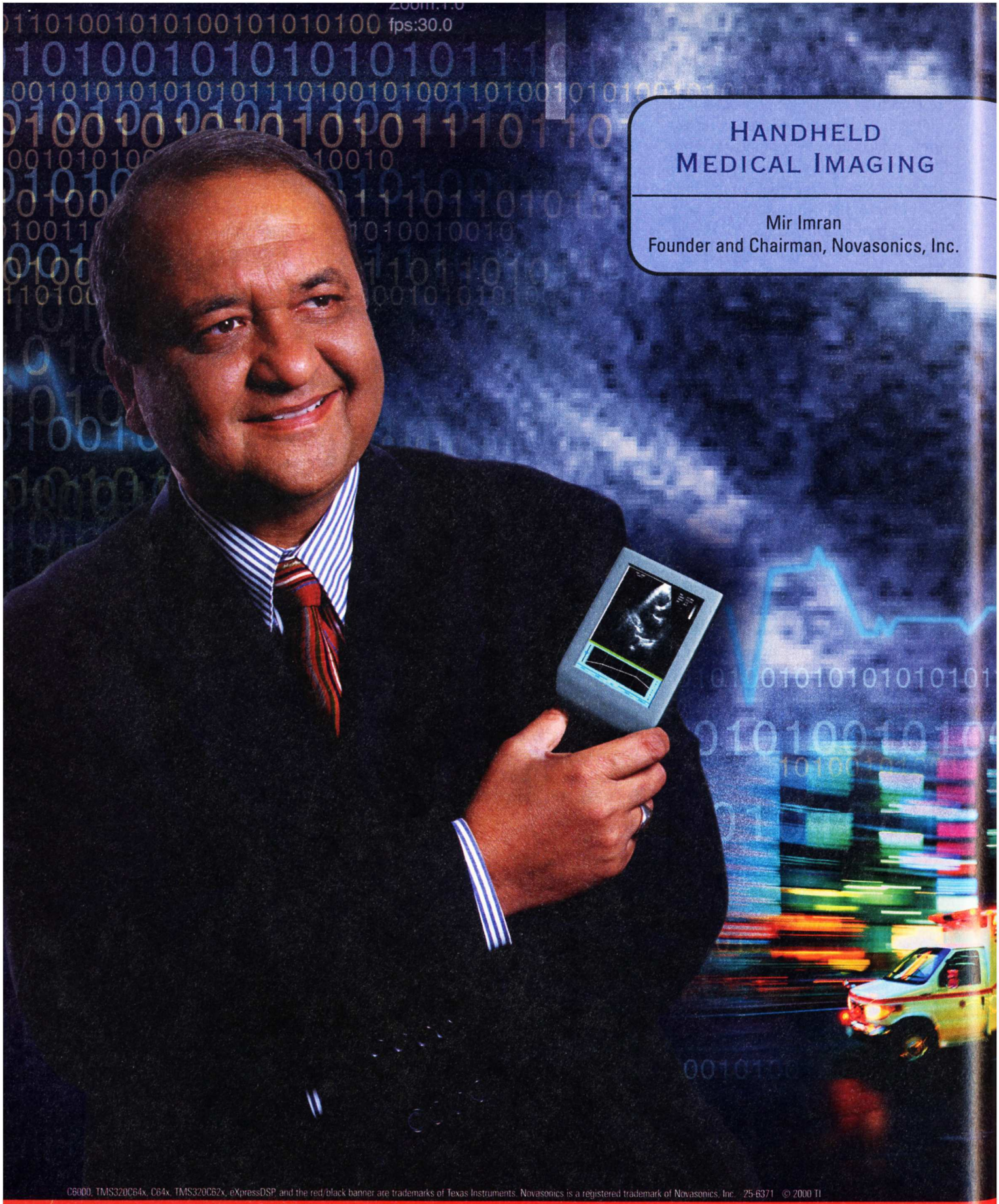
NEXT-GENERATION NETWORKS and devices could bestow on users an almost omniscient awareness—at least for items deemed personally important.

A desktop computer is an ally in thought, knowledge creation, new product design and exploration of the far reaches of the Web. Handhelds, by contrast, present a narrower slice of information that tends to support simpler decisions: Yes or no. Turn left or right. Alert if malfunction occurs. Vibrate if a specific stock reaches $42. It is no accident that Aether Systems and many other wireless companies got started in the financial industry, where simple, timely data triggers quick trades. According to Research In Motion, maker of two-way pagers with tiny keypads for mobile workers, nearly 80 percent of pages require a fast response. Mobile workers can respond directly with the device and get confirmation of messages received. But both timeliness and awareness seem to be getting more important in fast-paced business.

As handheld devices evolve, users will be able to choose their preferred way of getting this instantaneous information; they'll decide, for instance, whether they want to listen to information, read it or both. They will be able to reconfigure their factory-fresh devices with Java programs from the Internet, for instance. Devices could eventually subsume most of the functions of the paraphernalia people now feel compelled to carry with them: wallet, keys, address and appointment book, notepad, tape recorder. Personal medical monitoring functions and records might be added too.

As these devices find their way into every pocket and purse, they bring with them privacy issues. The small screens are peepholes into the Internet, arguably the largest assemblage of data ever. But can that portal be reversed by government or multinational corporations to build an intimate portrait of the user? Much of the value of digital companions boils down to getting relevant information at the right place or the right time. Yet getting such information often requires divulging preferences, voluntarily or tacitly. The better this information, the more personalized the service—but also the more exposed the user is to misappropriation of personal data. Moreover, wireless services that work by determining the user's location can open up scary possibilities. Do we really want to leave an electronic trail of our whereabouts and allow ourselves to be tracked like packages, revealing our preferences, income levels and habits all the while? Over the next several years, the challenge will be to design devices and networks to avoid pitfalls—while building a system so useful and benign that you won't ever want to turn it off. ◊

Handhelds' small screens are peepholes into the vast Internet. But can that portal be reversed to build an intimate portrait of the user?



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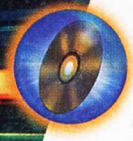
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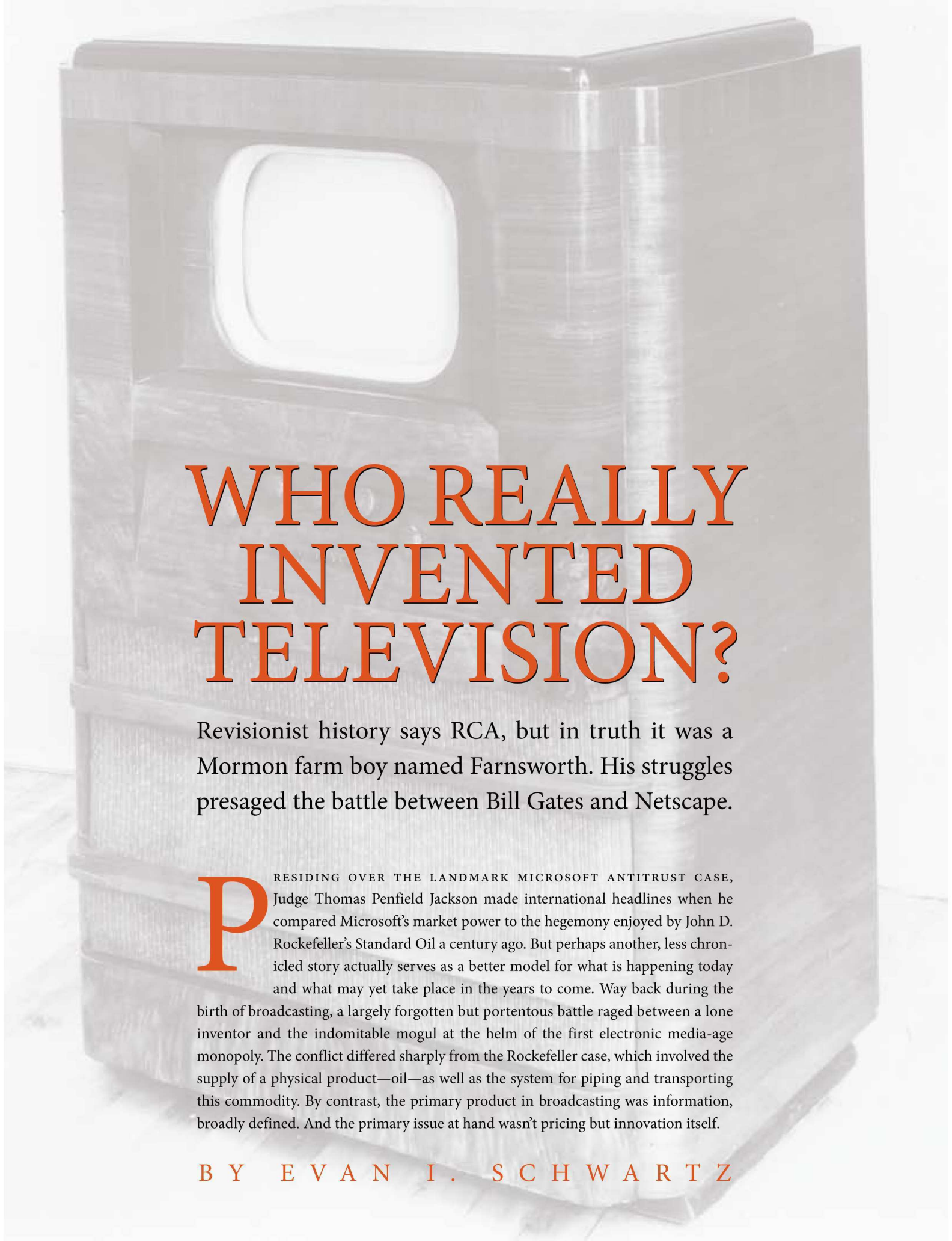
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WHO REALLY INVENTED TELEVISION?

Revisionist history says RCA, but in truth it was a Mormon farm boy named Farnsworth. His struggles presaged the battle between Bill Gates and Netscape.

PRESIDING OVER THE LANDMARK MICROSOFT ANTITRUST CASE, Judge Thomas Penfield Jackson made international headlines when he compared Microsoft's market power to the hegemony enjoyed by John D. Rockefeller's Standard Oil a century ago. But perhaps another, less chronicled story actually serves as a better model for what is happening today and what may yet take place in the years to come. Way back during the birth of broadcasting, a largely forgotten but portentous battle raged between a lone inventor and the indomitable mogul at the helm of the first electronic media-age monopoly. The conflict differed sharply from the Rockefeller case, which involved the supply of a physical product—oil—as well as the system for piping and transporting this commodity. By contrast, the primary product in broadcasting was information, broadly defined. And the primary issue at hand wasn't pricing but innovation itself.

BY EVAN I. SCHWARTZ



Intent inventor: In 1929, eight years after dreaming up electronic TV, Philo T. Farnsworth fiddles with a transmitter.





Lights, camera, action: Pem Farnsworth smiled under extremely harsh lights to star in some of the earliest TV transmissions (above). Philo Farnsworth and his secretary (left) admired the first mobile TV camera in 1934. The next year, the inventor was hard at work in the lab (below).



PHOTOS (OPENING SPREAD; THIS PAGE, LEFT AND TOP): FARNSWORTH FAMILY. THIS PAGE, BOTTOM: CORBIS IMAGES

Innovation in the early days of radio was controlled so tightly by David Sarnoff, the stocky, domineering, Russian-born visionary who led the Radio Corporation of America (RCA), that the federal government was compelled to investigate. What government trustbusters found was something that had been obvious to industry insiders for years: Sarnoff's company had an iron grip on every aspect of radio, from the patents on the device itself to the creation and distribution of programming. "Sarnoff was the Bill Gates of his age," says Thomas Lento, director of communications for the Sarnoff Corp., a Princeton, N.J., research lab spun off from RCA in the late 1980s. "RCA had a stranglehold over an entire sector of the economy." But it was Sarnoff's move to capture the next big thing, television, and his plot to destroy the ambitious young inventor behind the new technology, that sent sparks flying.

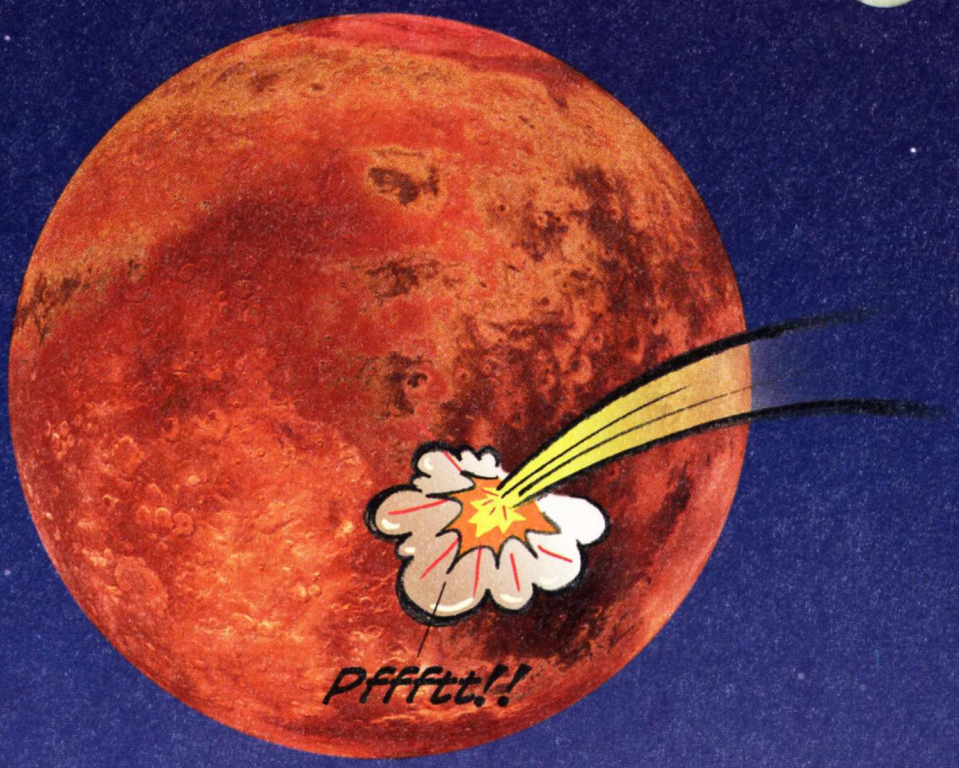
Just as Microsoft didn't invent the PC operating system, RCA didn't invent radio. The firm was formed in 1919 when General Electric purchased the U.S. subsidiary of the Italian inventor Guglielmo Marconi's original company. Sarnoff, who had worked at the American Marconi Company since his teens, was among the first to envision the news and entertainment applications of broadcasting.

Appointed RCA's commercial manager at 28, Sarnoff greatly expanded the original Marconi patent portfolio and made sure no one could legally manufacture or sell a radio set without paying RCA a stiff royalty, just as no one could later make or sell a so-called IBM-compatible PC without paying a fee for the use of Microsoft's MS-DOS and Windows. "The patents were all bundled together," Lento says. "If you wanted to make a radio, you had to license all of them."

And just as Microsoft used the infrastructure of Windows to propel its Office software to dominance, Sarnoff leveraged his advantage as radio's standards-setter to organize hundreds of local stations into a national network, founding his National Broadcasting Company (NBC) division in 1926 and making it the primary provider of free electronic news, music and sports.

The rewards of dominance were great. Over a span of 15 years, radio exploded, from the domain of a few thousand hobbyists to a fixture in most Americans' homes. Along the way, the RCA shares that GE issued skyrocketed. Multiplying more than 10,000 percent, RCA became the single hottest security in the great bull market of the Roaring Twenties—going from startup to component of the Dow even faster than Microsoft would accomplish the same feat decades later.

Then, on the evening of May 30, 1930, the Department of Justice served Sarnoff with a summons, interrupting a black-tie dinner at which the newly promoted RCA president was an honored guest. The charges: RCA was using its patent portfolio to restrain competition. Government antitrust action against RCA would drag on for almost three decades, sparking patent disputes, endless hearings and standards battles. There were also critical compromises, including a 1932 consent decree in which GE and



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FARNSWORTH FAMILY

Westinghouse agreed to sever all ties to RCA—a remedy Sarnoff privately favored. And the case led to new laws, foremost the 1934 act launching the Federal Communications Commission (FCC). But technology catapulted at such a terrific pace that the real battle was never fought in the federal arena, but in the marketplace.

IN THE MARKETPLACE, SARNOFF WAS ALREADY BECOMING less focused on his radio monopoly than on his attempt to extend it to the new frontier of transmitting moving pictures through the air. He only saw one major obstacle in his way: a Mormon farm boy named Philo T. Farnsworth. Born in 1906 in a Utah log cabin without electricity or a telephone, Farnsworth at age 6 declared his intention to become an inventor like his heroes Bell and Edison. The kid taught himself physics, studying Einstein's theories and reading borrowed science books and magazines late into the night. As a teenager, he worked part time repairing radios and thought constantly about the properties of something known as the electron.

From his reading, Farnsworth knew that several inventors had achieved limited success with a mechanical television system, transmitting images along a wire between two spinning disks with spiral rows of holes to pick up patterns of light at one end and project them at the other. But he figured, correctly, that such a setup wouldn't work fast enough to capture and reassemble anything but shadows and flickers.

According to surviving relatives, Farnsworth dreamed up his own idea for electronic—rather than mechanical—television while driving a horse-drawn harrow at the family's new farm in Idaho. As he plowed a potato field in straight, parallel lines, he saw television in the furrows. He envisioned a system that would break an image into horizontal lines and reassemble those lines into a picture at the other end. Only electrons could capture, transmit and reproduce a clear moving figure. This eureka experience happened at the age of 14.

Farnsworth's idea grew into an all-out obsession. In 1926, at age 20, he married a beautiful brunette named Elma "Pem" Gardner. The two boarded a train for California the next morning in order to be near Caltech and other centers for motion-picture sciences. They set up a makeshift television lab in the living room of their Hollywood apartment, moving a year later to an old warehouse at 202 Green St., on San Francisco's Telegraph Hill. Now backed by wildcatting bankers who foreshadowed today's Silicon Valley venture capitalists, Farnsworth was the 20th century's skinny, pale, brilliant proto-nerd.

When he demonstrated a working model of his television in 1928 for a group of reporters, he was only able to show blurry images on a tiny screen. But the system delivered 20 pictures per second, enough to convince the eye it was looking at motion rather than a series of stills. *The San Francisco Chronicle* lauded the achievement under the headline: "S.F. Man's Invention to Revolutionize Television," and the story was picked up by wire services and papers nationwide.

Sarnoff, of course, was tracking these activities from afar. But he needed a closer look. To get one, he hired a fellow Russian immigrant named Vladimir Kosmo Zworykin, head of television research and development at Westinghouse in Pittsburgh. Zworykin had been working on television for years. He filed for a theoretical patent on such a system as early as 1923—still pending seven years later—even though he had no working model. Farnsworth had applied for two key patents of his own; Zworykin had already been in touch with him about visiting the San Francisco laboratory. By then, Farnsworth's financial backers were putting pressure on him to sell the whole company—rather than just a license—to Westinghouse. After all, the stock market had recently crashed and burned.

RCA used its patent portfolio to quash competition and lay the foundation for a broadcasting monopoly.

"The bankers all wanted to cash out," recalls Pem Farnsworth, now 92 years old and living with her son, Kent Farnsworth, and his family in a small house in Fort Wayne, Ind. No stay-at-home wife, Pem had worked along with her brother Cliff on her husband's small lab staff. Despite the fact that these events took place some 70 years ago, her recollections seem sharp, especially when it

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comes to the colossal battles with Sarnoff.

"Dr. Zworykin was there for three days, and he saw everything," Farnsworth's widow says of that visit to the Green Street lab in April of 1930. Her husband even built an "image dissector," essentially the first electronic television camera, right before his guest's eyes. Farnsworth agreed to host the visit because he had hoped Westinghouse might license his patents for a substantial amount of money. Pem Farnsworth maintains that her husband didn't realize the full extent to which Sarnoff and Zworykin were already collaborating.

Sarnoff offered to buy Farnsworth out. The young inventor rejected the deal and ignited a legal firestorm.

Zworykin returned immediately to RCA's Camden, N.J., labs and began trying to reverse-engineer what he had seen at Green Street. Apparently confident he was backing the right guy, Sarnoff gave his new employee a $100,000 budget—many times greater than all the money Farnsworth had been able to raise—and a one-year deadline to develop a working electronic television system. But despite all Zworykin's knowledge and experience, the year came and went without much to show for it.

Frustrated by the lack of progress, Sarnoff decided to fly across the country and pay a surprise visit to the Farnsworth lab himself. It was April of 1931, and the RCA antitrust case had been droning on in Washington for months, making this trip all the more audacious. "At this point, RCA is in chaos," says Alex Magoun, director of the David Sarnoff Collection, an archive of historical documents, in Princeton, N.J. "Radio and phonograph sales were plunging. The Depression led to a price war and the $10 radio. The government forced RCA to slash its licensing fees. And RCA's stock lost more than 90 percent of its value. Sarnoff had this financial desperation. He was probably thinking, 'I'm going to buy this Farnsworth guy.'"

When Sarnoff arrived at 202 Green St., Farnsworth happened to be out of town on business. The door was answered by George Everson, a philanthropist who had several years earlier become the first backer of the Farnsworth Radio & Television Company. Everson proceeded to show Sarnoff around and had the engineers conduct a special demonstration. At the end of the visit, Sarnoff expressed confidence that he could build TVs without infringing on Farnsworth's patents and that there was nothing here that he needed, according to Everson's written account. But shortly thereafter, Sarnoff offered $100,000 to buy the company outright. Under the terms, Sarnoff would own Farnsworth's television patents, now formally granted, and Farnsworth would come to work for RCA. The episode portended a remarkably similar Microsoft visit to Netscape in 1995, in which top executives from Redmond allegedly threatened actions that could put the startup out of business unless it cooperated.

When Farnsworth received word of the deal by telegram, he rejected it. And despite the fact that bankers were looking for an exit, they agreed that the lowball offer was an insult. "The bankers were pretty dim," remarks Kent Farnsworth. "But even they could see more than a hundred grand in television."

The rejection brought the full wrath of the mogul down on the inventor. "Sarnoff decided to break him in patent court," says Pem Farnsworth. In other words, Sarnoff would do to Farnsworth what he did to those who had developed key radio inventions but had refused to cooperate fully with RCA. Sarnoff and his team of lawyers would launch a legal assault aimed at overturning the patents on appeal, which would tie up the inventors emotionally and financially for years. "That was RCA's M.O. at the time," says Kent Farnsworth.

The legal challenges to Farnsworth's basic television-system patents lasted for nearly four years. They slowed development of television, delayed its introduction to the public, squandered the company's already thin resources, drove Farnsworth to drink, and contributed to his developing a bleeding ulcer.

Sarnoff's mischief didn't end there. At the time of his visit to Green Street, Farnsworth was trying to make an end run around RCA, meeting with Philco's senior executives on the East Coast. Philco was the largest manufacturer of radio sets in America, selling more units than RCA. But every time there was a flurry of publicity around television, its stock would drop. Investors saw television as the next big thing, and Philco wanted in. So it agreed to take out a license from the Farnsworth Company and produce TV sets—until Sarnoff stepped in.

Sarnoff and Zworykin learned of the collaboration by picking up test transmission signals from Philco headquarters, which sat just across the river from RCA's Camden labs. Sarnoff threatened to rescind RCA's patent licensing arrangement with Philco, according to Pem Farnsworth—just as Microsoft would, decades later, allegedly use the Windows license to keep PC makers exclusively loyal to the company. Without that license, Philco would no longer be able to produce radios legally, and its

A TV Timeline

1919
GE forms RCA when it swallows the U.S. assets of the Marconi Company.
David Sarnoff, age 28, becomes RCA's first commercial manager.

1921
Philo T. Farnsworth dreams up the idea for electronic television while plowing a potato field in Idaho. He is 14 years old.

1926
Sarnoff forms NBC as a wireless relay network, thus controlling not just the technology of radio, but also its content and its distribution.

1928
Farnsworth holds a press conference to show off the first two-dimensional electronic television transmission.

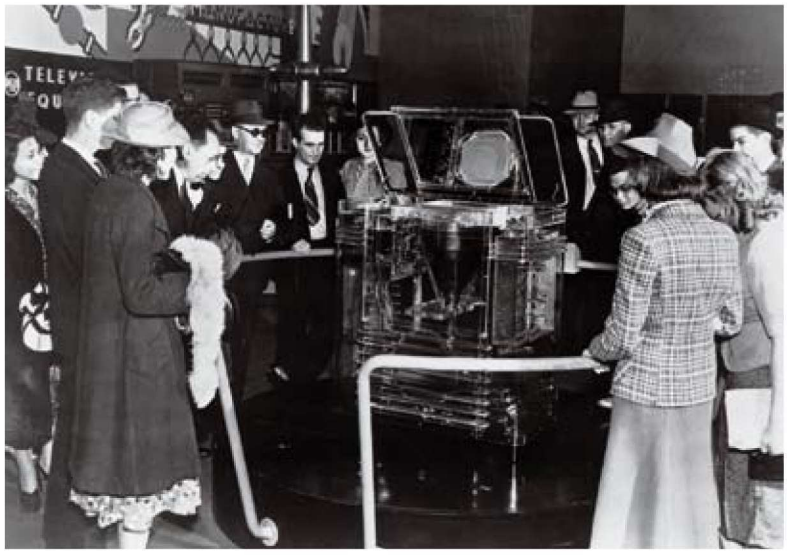
1930
Farnsworth's key TV patents are granted.
Sarnoff sends Vladimir Zworykin to visit Farnsworth's lab in San Francisco.
The U.S. Justice Department charges RCA with anticompetitive behavior.

1931
Sarnoff personally visits Farnsworth's lab. His offer to buy the Farnsworth Radio & Television Company for $100,000 is rejected.





Fair play? RCA touted Vladimir Zworykin (above) as TV's inventor. Sarnoff (top right) used the 1939 World's Fair to introduce the nation to RCA television (bottom right) and to make Franklin D. Roosevelt the first president on TV (below).





PHOTOS (THIS PAGE) DAVID SARNOFF LIBRARY

core business would be gone. So Philco was forced to break off its dealings with Farnsworth, leaving him without a major U.S. customer. That's the Farnsworths' version of the story, anyway; RCA naturally doesn't admit to such foul play. "There could have been a threat [from Sarnoff to Philco]," says Magoun. "But we don't know that."

By 1934, the patent dispute had reached high drama. RCA had appealed on the grounds that Zworykin's 1923 application should be awarded priority. Dozens of RCA lawyers were at work on the case before the final hearing. The testimony and the evidence were complex, and the court's examiners took an extra 10 months to complete their ruling. Finally, in July 1935, the decision was mailed to all involved parties.

When Farnsworth started reading the 48-page document, his heart must have sunk. "Farnsworth only has oral testimony prior to 1923," the ruling read, "from him and from witness Justin Tolman." Tolman was Farnsworth's high-school science teacher in Idaho, and Farnsworth had bounced the idea of elec-

1935
Sarnoff's attempt to overturn the Farnsworth patents fails, as an appeals court awards Farnsworth "priority of invention."

1939
Sarnoff announces at the World's Fair in April that NBC will begin regular TV broadcasting. Farnsworth agrees to license his TV patents to RCA for $1 million in September.

1947
Farnsworth's television patents begin to expire while TV use and programming explode nationwide.

1949
Farnsworth sells his company's assets to ITT.

1971
Farnsworth dies in obscurity at age 64. "General" David Sarnoff dies at age 80, heralded as a visionary and pioneer.

1982
Zworykin dies a wealthy man, lauded as the father of television.





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Color wars: By the mid-1950s, RCA had crushed the competition in color broadcasting (above), and color TV sets were in mass production (left).

tronic television off him one day after school. But the patent examiners wanted hard evidence. "The original [diagrams of the TV system] were drawn on a high school blackboard and erased, or if drawn on paper, destroyed."

Still, the ruling also took issue with Zworykin's claims. Mainly, it said that a machine built according to his 1923 design would produce largely meaningless shades of darkness and light. "The Zworykin application, as filed, does not disclose a device for producing an electrical image which is scanned to produce television signals as required," the ruling said. As a result, the Farnsworth patents withstood the challenge. "Priority of invention is awarded to Philo T. Farnsworth," the ruling concluded. At 29, Farnsworth was now the undisputed inventor of television as the world would come to know it.

Sarnoff may have lost the battle, but he was determined to win the war. He knew that timing was everything, and that the public had to be sold on TV. The 1939 World's Fair was soon approaching, an event that was to become one of the biggest and most celebrated expositions in the history of the world. Sarnoff knew that most of the public still had never seen a television, despite the fact that the Farnsworths were touring the country and showing it off publicly.

Sarnoff had been deploying every financial, scientific and legal resource at his disposal to recreate Farnsworth's TV. He had consolidated the top scientists from four companies—RCA, Westinghouse, GE and the Victor Talking Machines Company—at his Camden lab. By 1939, he too had a working model, even though he had never paid Farnsworth a dime in licensing fees.

To gain the advantage, Sarnoff orchestrated a public-relations masterstroke. Not only did RCA sponsor the World's Fair Television Pavilion in New York City's Flushing Meadow, but Sarnoff had also secured the rights to host and broadcast the opening ceremony, on radio and on its newfangled successor. He stocked New York department stores with newly minted RCA models.

The publicity leading up to the big event reinforced the stature of RCA. *The New York Times* asked Sarnoff to contribute an authoritative essay about the fair in a special section of the newspaper. *Life* magazine pictured RCA executives huddled around their newest model television, not mentioning that it may have been built illegally. Sarnoff billed the event as the beginning of commercial television broadcasting—a misleading claim, since in 1934 Farnsworth had conducted a 10-day series of broadcasts from Philadelphia's Franklin Institute. Furthermore, in 1936, the Olympic games were broadcast live from Munich using equipment a German company had built under license from Farnsworth. But only a few dozen people in Germany had TV sets at the time and, since satellites had not yet been invented, the signal didn't reach other nations.

At a press conference before the opening of the fair, Sarnoff strutted up to the podium, camera flashes bouncing off of his high forehead. "It is with a feeling of humbleness," Sarnoff began, "that I come to this moment of announcing the birth in this country of a new art so important in its implications that it is bound to affect all society. Now, ladies and gentlemen," he declared, with a grand flourish, "we add sight to sound!" Then he announced that RCA's own NBC broadcast network would begin regular television broadcasts live from Radio City Music Hall. Several days later, at the opening ceremony, Franklin D. Roosevelt became the first president to be televised.

The ballyhoo of the event turned Sarnoff's stunt into an official, historic event. The gathered throngs of media ate it up and reported it far and wide. "Last week, of course, witnessed the official birth of television," reported *The New Yorker.* RCA was responsible for bringing us television. This was the new reality that the public perceived.

"We could have sued his pants off," says Pem Farnsworth. But her husband was hoping to license the rights for producing televisions to RCA at the time. The plan was to maintain closely the patent ownership inside the Farnsworth Company, but to charge RCA and dozens of other companies an ongoing percentage on the sets that they would sell. So as not



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to disrupt any negotiations, Farnsworth decided to avoid any legal action. And he ended up selling RCA a $1 million license later that year.

DURING WORLD WAR II, THE U.S. GOVERNMENT suspended manufacturing of consumer electronics entirely. But Sarnoff, now dubbed "the General" by Dwight D. Eisenhower in recognition of his wartime assistance, was already marshalling his forces for the expected postwar boom. "He drummed up the marketing bandwagon," says Magoun. Right after the war, Sarnoff went on the road to convince his NBC radio affiliates to begin airing NBC television programs. Government regulators were trying to keep up, and the FCC forced RCA to divest half its broadcast holdings, leading to the creation of ABC.

Reeling from years of severe stress, Farnsworth suffered a nervous breakdown and was bedridden for several months before the war. Afterward, he and Pem relocated to Fort Wayne, where his new factory began volume production of television sets. But time ran out. Farnsworth's key patents expired in 1947, just a few months before TV began a sudden, rapid proliferation from just 6,000 sets in use nationwide to tens of millions by the mid-1950s. RCA captured nearly 80 percent of the market, while Farnsworth was forced to sell the assets of his company to International Telephone and Telegraph, an industrial conglomerate that quickly decided to exit the commercial TV business.

Farnsworth's story is tragic, but he wasn't the only casualty of Sarnoff's delay tactics. In the late 1940s, Sarnoff sued to prevent CBS from broadcasting in color—a technology both RCA and CBS were racing to develop—on the grounds that it would disrupt the market for black-and-white television. In 1951, the Supreme Court finally ruled in favor of CBS. By then, RCA had seeded the market with millions of its black-and-white sets. Meanwhile, in RCA's labs, Sarnoff launched a crusade to devise an even better system for color, so as to control the all-important standard for transmission and marginalize the CBS format. A main bragging point was so-called backwards compatibility. Only RCA color broadcasts could be translated for viewing on the RCA black-and-white sets that most people had. If viewers wanted to watch CBS color broadcasts, they had to buy a special adapter for $100. It was similar to the unique position Microsoft would hold many decades later, when it would be the only company that could create a format, Windows, that could execute older MS-DOS programs.

When the FCC and the National Television Standards Committee made RCA's color transmission standard the official one, Sarnoff took out full-page newspaper ads declaring his "great victory." Like the first version of Microsoft Windows, however, RCA color wasn't a big seller initially. But Sarnoff kept at it until the marketplace came around. So by the time RCA entered into a landmark consent decree with the Justice Department in 1958, agreeing to license its color TV technology freely to anyone for a reasonable price, the color war was over and RCA had crushed the competition—again.



KENT M. FARNSWORTH

Out of time: Farnsworth, shown above with his wife Pem near the end of his life, died in 1971. He was broke, depressed and largely forgotten.

AS SARNOFF STEAMROLLED HIS COMPETITORS, HE REWROTE history. RCA took every opportunity to trot out Zworykin as "the father of television." Philo T. Farnsworth became the answer to an obscure trivia question. "The RCA public-relations department did a number on us," says Pem Farnsworth. Both Sarnoff and Farnsworth died in 1971, and the contrast couldn't have been greater. Farnsworth was broke, severely depressed and largely forgotten; Sarnoff was celebrated as a pioneer and visionary—and who could argue?

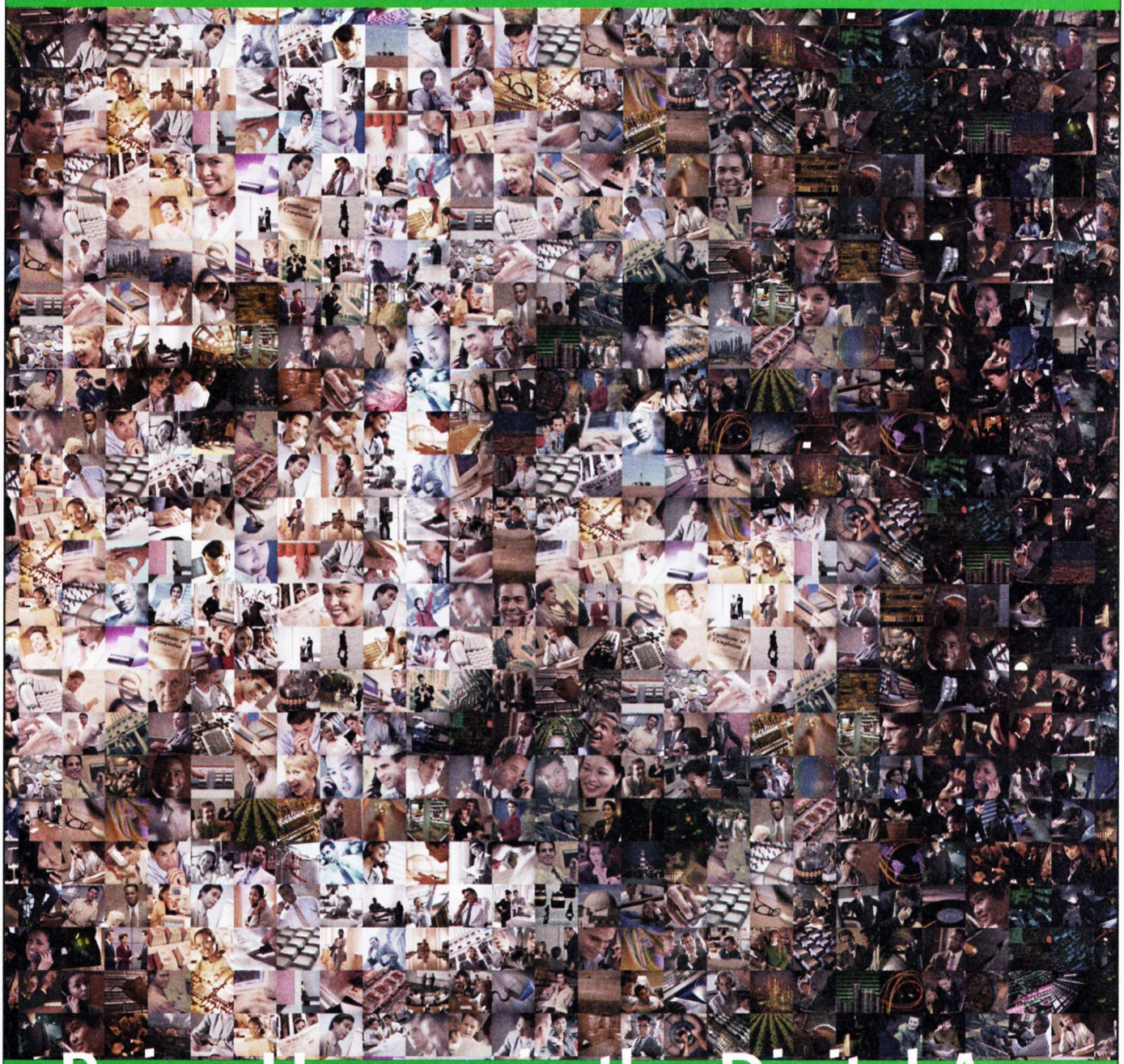
Like many moguls, Sarnoff believed that his actions were justified. "Sarnoff saw his monopoly power as a force for good," says Magoun. "He took it very seriously. He hired the best engineers and took their word as to what was the best approach. Yes, he made enemies. But even if we say he did trounce people, it wasn't as explicit as some would assert." No doubt, the same could be said about Bill Gates. The subtle undercurrent in both Gates' story and Sarnoff's has to do with the control of innovation. Each man was known to appropriate ideas and technologies developed elsewhere, delaying their dissemination while his company tried to perfect them. But did consumers suffer because of this? While competitors would no doubt disagree, those who defend the moguls argue that it's beneficial to have one company control the pace of innovation. "Why do we assume that the more rapid the innovation is, the better it is for the consumer?" asks Magoun. "Why do we want endless, uncontrolled change in the way we live our lives?"

From David Sarnoff to Bill Gates, the technology monopolist has one powerful force on his side: time.

And that leads us to the overarching parallel between these two eras. The government spent 28 years trying to rein in RCA, and has pursued the Microsoft matter for more than a decade already. In both cases, the defendants used the intervening years to expand greatly the scope of their dominance. Which goes to show that the technology monopolist has one all-powerful force working to his advantage. Not ingenuity or technological superiority. Not legal firepower. Not even money. Unless it is somehow taken away by force, what the monopolist has on his side is time. ◊

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Tom Leighton has the formula for going from MIT math professor to Internet gazillionaire.

Akamai's Algorithms

Q & A

YOU DO THE MATH. TOM Leighton, a professor at MIT's Laboratory for Computer Science, or LCS, holds nearly 10 million shares in Akamai Technologies, a company he co-founded in August 1998. Last October, Akamai went public, with prices at the initial public offering (IPO) starting off at $26 a share; by the end of the day, investors had bid the price up to $145 a share. A month later the stock was selling at $327 a share. No matter how much math anxiety you might have, you get the point—Tom Leighton had become a very rich man.

An academic whose expertise is in parallel algorithms and applied mathematics, Leighton is at first glance an unlikely candidate for an Internet tweeds-to-riches success story. But on closer examination, it makes perfect sense. For years, Leighton has been scrutinizing how complex networks operate—and how they can be optimized. So, five years ago, when Tim Berners-Lee (the inventor of the World Wide Web) came down the hall at LCS looking for ways to better manage the escalating traffic flow on the Internet, Leighton and his crew of graduate students were an obvious place to drop in.

During the next several years, Leighton and a mix of MIT graduate students and undergrads tried to figure out a better way to manage and distribute content over the Web. In early 1998, the group, which included grad student Daniel Lewin (who along with Leighton and Jonathan Seelig, a student at MIT's Sloan School, went on to found Akamai), entered the MIT $50K Entrepreneurship Competition. The team was a finalist but didn't win. Still, the venture capitalists came knocking. And the rest is Internet history. Today the company runs a worldwide network of more than 4,000 servers that distributes Web content for such customers as Yahoo!, CNN and C-SPAN; if a PC user requests, for example, videostreaming from C-SPAN's Web site, the Akamai system of servers helps to deliver that content, thereby avoiding bottlenecks at C-SPAN's centralized site. The distributed network makes content delivery over the Web quicker and more reliable.

Despite hitting the IPO jackpot, the soft-spoken MIT professor (currently on a leave of absence from LCS) displays few overt signs of material success. At Akamai's new headquarters adjacent to the MIT campus, Leighton, the company's chief scientist, occupies a modest corner office overseeing a maze of cubicles. It's very much the office of a professor, and Leighton speaks in the patient and precise words of someone used to explaining how things work. *TR* Senior Editor David Rotman recently went over for a lesson on managing traffic on today's Internet.

PHOTOGRAPHS BY JOHN SOARES

TR: When did it occur to you that you could use algorithms to optimize content delivery on the Web?
LEIGHTON: The first time I ever thought about the Internet was in 1995. My office [at MIT's LCS] is down the hall from Tim Berners-Lee and the Web Consortium. Over time we talked about some of the issues facing the Internet. These are the kinds of large-scale networking problems that our group was working on and that I have a long-term interest in. So we took on some of them as research projects.

TR: In a sense, the Internet is really the ultimate networking challenge, isn't it?
LEIGHTON: Yes. That's right.

TR: What was the problem that you started with in '95?
LEIGHTON: We were looking at ways to deal with flash crowding and hot-spotting. That's where a lot of people go to one site at one time and swamp the site and bring down the network around it—and make everyone unhappy.

TR: Can you explain the technologies you've developed?
LEIGHTON: Today we're probably one of the world's largest distributed networks. At a high level, we're serving content or handling applications for end users, and we're doing that from servers that are close to the end users. "Close" is something that changes dynamically, based on network conditions, server performance and load. Because we're close, we can avoid a lot of the hangups, delays and packet loss that you might experience if you're far away. Before, you typically got your interaction with a central Web site. And typically that was far away. Now you typically have a lot of your interactions—not all, but a lot—with an Akamai server that is near you and is selected in real time.

TR: What are the tricks and challenges to making this distributed system work?
LEIGHTON: It's an extremely hard area; you can't go and just throw a bunch of servers out there and have them all work with each other. The servers themselves are going to fail. Processors are going to fail. The Internet has all sorts of its own issues and failure modes. So all these kinds of things have to be built into the algorithmic approach. How do you develop a decentralized algorithm with imperfect information that is still going to work? That's a huge challenge. But it's clearly what you have to do. You can't have any central point of failure or the system will come down. I can't think of a component or a piece of hardware that hasn't failed at some point or some place. So, it's a given [that you need a distributed system].

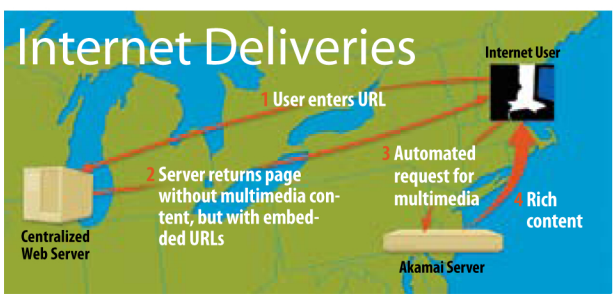
When a client comes to one of our customers looking for content, we have to figure out where that client is, which of our locations at that moment is the best to serve the client from, and what load conditions are, so we don't overload anything. We have got to handle flash crowds that are both geographic and content specific. We have got to replicate the content immediately to handle any of those kinds of issues, but you can't afford to have copies of everything everywhere. You've got to make these decisions and respond back to the clients in milliseconds. We've got to be automatic. And when pieces fail, you've got to compensate automatically for that.

TR: That's what you call fault tolerant?
LEIGHTON: Yes, and you have to be fault tolerant across all aspects. Then there are also the non-obvious things. Like billing. We're serving billions of hits a day, and we're billing for every single hit. We've got to figure out whose content it was and how many bytes it has, and bill them for it. On top of that, we have a service that we offer our customers, where they can see within 60 seconds how many hits we served for them in the last 60 seconds. In addition, we can break down for our customers where the hits are coming from by country or state. It's a challenging algorithmic problem. How do you actually do that? And make it work with a finite amount of hardware and resources?

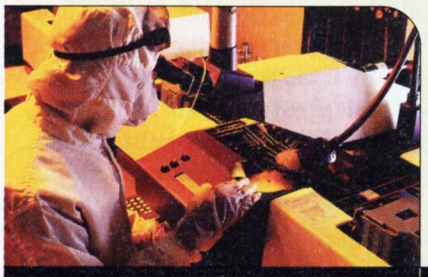
TR: Hardware isn't really the key to this, is it?
LEIGHTON: It's not even a major component. I don't want to belittle our hardware partners, but the key here is the algorithmic and software infrastructure. It's critical.

TR: What is your competition in offering a distributed network for content delivery?
LEIGHTON: There's not really much out there. We're at a time when there's a lot of business plans and there's a lot of stories. There's not much in the way of real services available today. Pretty much the only competitor in our space is Digital Island, which recently acquired Sandpiper [Networks]. There are others that have announced [business plans] but are not actively carrying traffic yet. One of the things that distinguishes Akamai is the amount of research and engineering and R&D effort that went into designing the system. It's not just throwing a bunch of boxes out there. There are companies that have tried do that with no distributed system. The companies that announced services based on that approach two or three years ago aren't still in business. Doing that didn't work.

TR: What are the upcoming challenges for the technology? Is it to deliver content faster?
LEIGHTON: That's a component. We're trying to deliver on the promise of the Internet. There is the idea that there is a tremendous revolution happening with regard to the Internet. At the same time, there's frustration because of the limitations. What we're trying to do is to make the Internet more useful. And a component of that is making it faster and more reliable. Another component, somewhat related, is enabling the delivery of more enriching, more enabling content. If we can make streaming better, and in this case speed is not so much the issue, it's bandwidth and not having packet loss, you're going to get a much better image on your screen; you'll do more with it, and more people are going to use it to convey content and information. And that's invaluable in enriching the power of the Internet.



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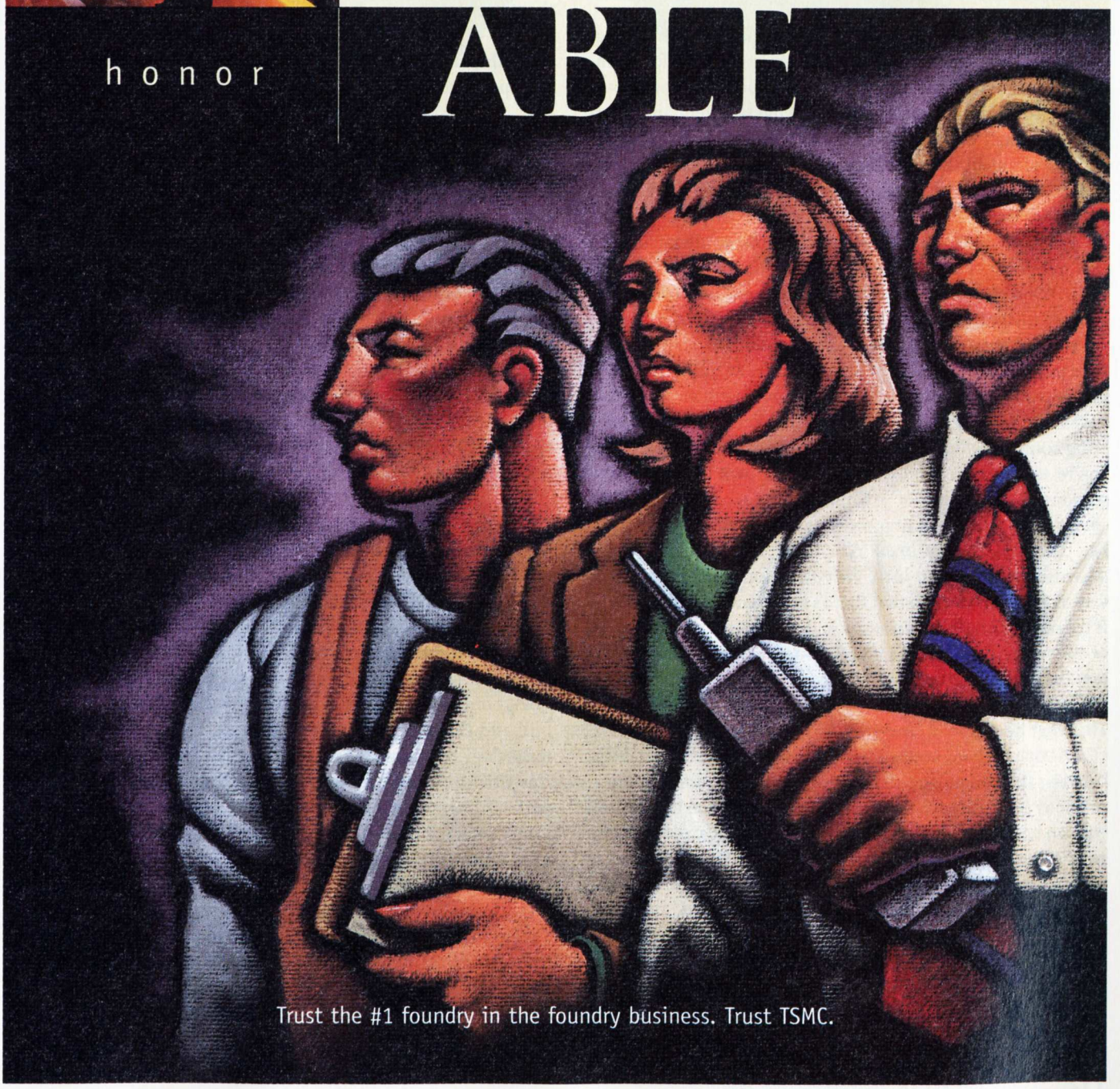


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But not everything is pushing bits. Akamai offers services for capabilities such as Internet conferencing that enable, for example, distance learning. With these services, content providers or enterprise customers can effectively deliver content and interact with small or large audiences on the Web through live audio and video; there are features for sharing presentations, audience polling and moderating messaging.

TR: When you introduce a new function like conferencing, for example, what demands does it place on the network?
LEIGHTON: How are you going to implement it? How are you going to integrate it into this massive distributed platform? How are you going to maintain it for thousands of customers? You have thousands of customers and hundreds of millions of people accessing those customers, and we're sitting in between. And it all has to work by itself. You can't be monkeying around. Delivering conferencing sounds simple. But it's not so simple when you're talking this kind of scale. When people think about streaming they think of a single source where the content comes from, and then it branches out in a tree through the Internet. Those places can break down and then all those people downstream are out of luck. We've developed an entirely new way of going about it so that there's no critical point of failure. If the source dies, then you're stuck. But once [the content] is out of the source, we replicate it and spread it throughout the system. So, it's not a tree.

TR: What does it look like?
LEIGHTON: It's hard to describe. The way to think about it is that between the source and destination, you have multiple transmissions going on such that you can lose content on those paths; you can have packet loss on any or all of them, but at the endpoint you have enough information coming in from those locations so you can reconstruct the signal. So, if something gets killed along the way, such as a path gets killed, nobody's affected.

TR: We've all experienced frustrations with videostreaming. In terms of the technology, what will it take to make it more reliable? When will we be able to watch webcasts as easily as TV on a full screen?

LEIGHTON: In order that videostreaming be more reliable, you need a content distribution service to deliver the bits reliably to the edge of the network, and then you have to have a reliable last-mile connection to the Internet. If you want high-quality video, then you better have a high-bandwidth connection to the Internet. It will still be some time before you can get TV-quality videostreams on a widespread basis.

We've demonstrated a megabit-per-second live stream. In fact, just recently we carried thousands of one-megabit-per-second streams to live customers accessing a conference keynote address by Steve Jobs [CEO of Apple Computer]. This is a major milestone for the Internet. With that technology you get a very high quality videostream. If the last mile is broadband, then you're all set to go. One thing we're working on is bandwidth profiling. The idea is to automatically detect the bandwidth of the last mile. Does the client have a broadband connection, a 28K modem, or is it narrow band—a cell phone or something? Then we deliver the content as a function of that. So if you detect that the client has high bandwidth, they get the high-bandwidth version—the streamed version as opposed to the static version. Or in the case of narrow bandwidth, you get a printed version as opposed to the graphics.

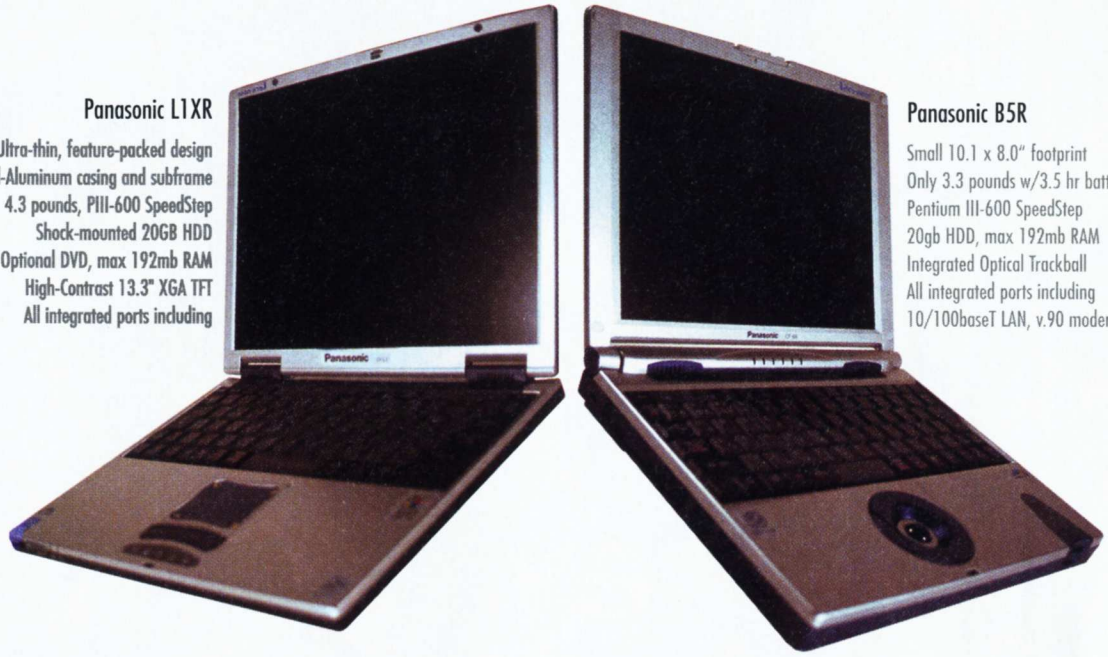
TR: The very nature of the Web seems to be changing with such functions as videostreaming and conferencing. What will Akamai be working on in five years? What do you think the Internet will be like then?
LEIGHTON: Things move so fast, it's really hard to predict. People who try to predict end up eating their words. I think we're just at the beginning of the Internet revolution. I don't think we've even begun to think of all the things that we can be doing on the Internet. I can't tell you what will be the hot service five years from now. I don't know. I would hope by then that, for example, the quality of streaming is much better. That it's part of daily life. At the least, I would expect the typical Web experience to become richer, more efficient and more reliable than it is today.

TR: You are seen by many as a model of an academic making it big as an entrepreneur in the new economy. What do you tell those looking to emulate your success?
LEIGHTON: I never had an aspiration to be an entrepreneur. I love academics and co-founded Akamai because we felt it was the best way to transfer our technology from a research environment into practice. It felt really nice to be taking technology, especially technology out of a university, and making a difference with it. That's probably the biggest reward. It often takes 10 to 20 years for a technology in a university to really manifest itself in practice. And this time we're able to decrease that time dramatically. I'm perfectly happy writing a paper that only five people read. Pretty smart people will read it, and I get a kick out of that. It's what I spent all my life doing. But this is something with a chance to make a difference.

TR: Do you ever miss the days when, as you put it, you spent your time writing papers that maybe five people were able to read and understand?
LEIGHTON: Yes, although I don't have much time to think about it. ◊

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Botstein's Caveat

We've come a long way from the babbling Brook Inn. That's the hostelry in Santa Cruz, Calif., where a handful of dreamers—and a few skeptics—gathered in May of 1985 and hatched what ultimately evolved into the Human Genome Project. You'd never guess by the hosannas of press coverage in June, when the first rough draft of the human sequence was announced, that the idea initially had struck everyone as ridiculous.

To those of us who have watched this effort unfold over the past 15 years, it's been surprising, and a little demoralizing, to see the early history of the project subsumed in the entrepreneurial brinksmanship, historical amnesia and Orwellian newspeak of contemporary science.

Biologists celebrated the "completion" of the sequence, yet it is incomplete—perhaps significantly incomplete. We were told a great race had taken place, but we allowed the participants to concoct a self-interested finish line, with no referees to certify the degree of completion or quality. We were frequently reminded of the lone-wolf virtuosity of J. Craig Venter, whose company, Celera Genomics, took on the Whole Government and won; we were too infrequently reminded that the race took place only after the public consortium had spent years clearing the brush and grooming the track.

As geneticist David Botstein warned way back at the beginning, completion of the Human Genome Project doesn't mean that much. The hard part is exploiting the results.



It's worth revisiting the Santa Cruz meeting and its cast of characters, therefore, to see how much—and how little—things have changed. The meeting was organized by biologist Robert Sinsheimer, then at the University of California at Santa Cruz, who was the first person to popularize the endeavor as "biology's moonshot." Leroy Hood, then of Caltech, became excited by the prospect of developing automated machines for such a project. Wally Gilbert, who helped develop some of the original sequencing techniques in his Harvard lab, riled the multitudes when he spoke of copyrighting—*copyrighting!*—the human genome and then selling the information to drug companies. The nerve of the guy!

And then there was David Botstein. This curmudgeonly geneticist, then at MIT, raised the most prophetic objection of all. Having the entire human sequence, he argued, was like having a complete set of Egyptian hieroglyphics and no Rosetta stone. Without the sequence of other organisms for comparison, especially the mouse (which we are still waiting for), the human sequence remains largely unreadable. And that is where we stand today, several months after the greatest achievement in the history of biology. We have 3.1 billion letters of human DNA in hand, and we're still functional illiterates when it comes to reading the text.

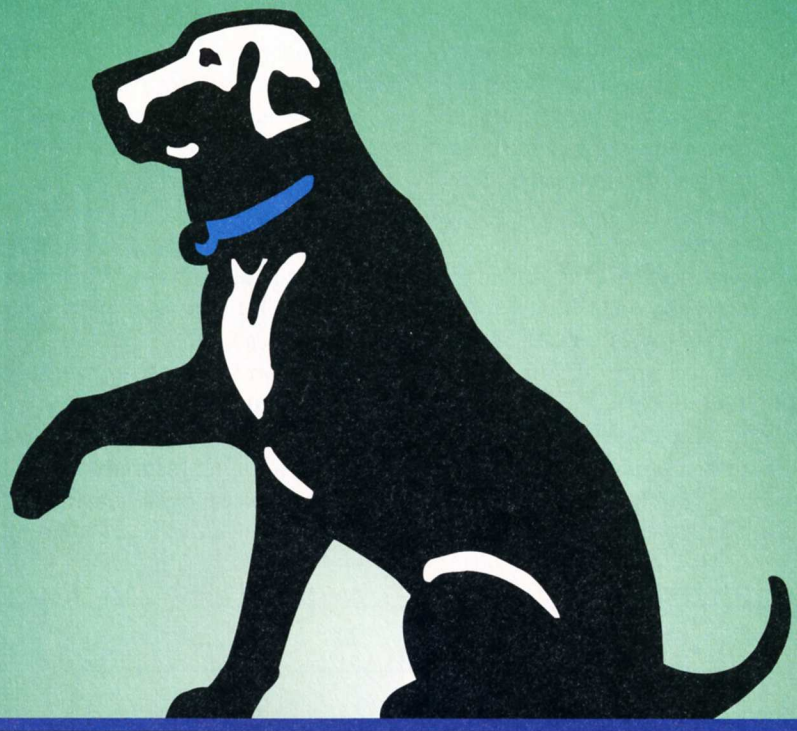
Now about that famous race. Despite the negotiated "draw," the general spin seems to be that Celera Genomics won. But Arnold Levine, president of Rockefeller University, shrewdly observed recently that Celera had a great advantage by entering the race when it was nearly over. Part of that advantage was technological, the other cultural.

Back in the days of Santa Cruz, sequencing was universally perceived as factory-style "big science," utterly devoid of creativity. It seemed so dull that only when the Department of Energy looked poised to take over the project (and, many feared, turn it into a political boondoggle) did the National Institutes of Health reluctantly become involved. Once the government committed $3 billion to the 15-year project, a huge economic infrastructure grew up around the endeavor.

Lee Hood, meanwhile, left the Santa Cruz meeting more convinced than ever that DNA sequencing machines had a future; Michael Hunkapiller, a postdoc in Hood's lab, went on to become the unheralded da Vinci of DNA in this whole story, designing wondrous machines at Applied Biosystems, which later became P.E. Biosystems. And it was Hunkapiller who called Venter in 1998 and convinced Celera that with the latest generation of machines, it would be possible to sequence the human genome much sooner than originally thought.

If I were a biologist, I'd be a little nervous right now about having raised public expectations unrealistically. The genome project will indeed revolutionize medicine. The question is: When? We've been reading advance excerpts from the "book of life" for years and haven't been able to make much sense of it. Ask the people with sickle-cell anemia: The exact molecular nature of that genetic disorder has been known for 25 years, and still no cure.

Therefore the most interesting question now is the time frame in which this future unfolds, and whether the public has the patience to await the fruits so extravagantly promised in June. On the day the sequence was announced, I called up David Botstein and asked if "biology's moonshot" warranted all the fuss. "We've flown around the moon," he said with a laugh, "but we haven't actually landed on it, and we haven't collected anything yet." ◊



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VIEWPOINT | BY HENRY JENKINS

Art Form for the Digital Age

Video games shape our culture. It's time we took them seriously.

LAST YEAR, AMERICANS BOUGHT OVER 215 million computer and video games. That's more than two games per household. The video game industry made almost as much money from gross domestic income as Hollywood.

So are video games a massive drain on our income, time and energy? A new form of "cultural pollution," as one U.S. senator described them? The "nightmare before Christmas," in the words of another? Are games teaching our children to kill, as countless op-ed pieces have warned?

No. Computer games are art—a popular art, an emerging art, a largely unrecognized art, but art nevertheless.

Over the past 25 years, games have progressed from the primitive two-paddles-and-a-ball Pong to the sophistication of Final Fantasy, a participatory story with cinema-quality graphics that unfolds over nearly 100 hours of play. The computer game has been a killer app for the home PC, increasing consumer demand for vivid graphics, rapid processing, greater memory and better sound. The release this fall of the Sony Playstation 2, coupled with the announcement of next-generation consoles by Nintendo and Microsoft, signals a dramatic increase in the resources available to game designers.

Games increasingly influence contemporary cinema, helping to define the frenetic pace and model the multi-directional plotting of *Run Lola Run*, providing the role-playing metaphor for *Being John Malkovich* and encouraging a fascination with the slippery line between reality and digital illusion in *The Matrix*. At high schools and colleges across the country, students discuss games with the same passions with which earlier generations debated the merits of the New American Cinema. Media studies programs report a growing number of their students want to be game designers rather than filmmakers.

The time has come to take games seriously as an important new popular

art shaping the aesthetic sensibility of the 21st century. I will admit that discussing the art of video games conjures up comic images: tuxedo-clad and jewel-bedecked patrons admiring the latest Streetfighter, middle-aged academics pontificating on the impact of Cubism on Tetris, bleeps and zaps disrupting our silent contemplation at the Guggenheim. Such images tell us more about our contemporary notion of art—as arid and stuffy, as the property of an educated and economic elite, as cut off from everyday experience—than they tell us about games.

New York's Whitney Museum found itself at the center of controversy about digital art when it recently included Web artists in its prestigious biannual show. Critics didn't believe the computer could adequately express the human spirit. But they're misguided. The computer is simply a tool, one that offers artists new resources and opportunities for reaching the public; it is human creativity that makes art. Still, one can only imagine how the critics would have responded to the idea that something as playful, unpretentious and widely popular as a computer game might be considered art.

The trouble with video games isn't that they're violent but that they're banal, formulaic and predictable.

In 1925, leading literary and arts critic Gilbert Seldes took a radical approach to the aesthetics of popular culture in a treatise titled *The Seven Lively Arts.* Adopting what was then a controversial position, Seldes argued that America's primary contributions to artistic expression had come through emerging forms of popular culture such as jazz, the Broadway musical, the Hollywood cinema and the comic strip. While these arts have gained cultural respectability over the past 75 years, each was disreputable when Seldes staked out his position.

Readers then were skeptical of Seldes' claims about cinema in particular for many of the same reasons that contemporary critics dismiss games—they were suspicious of cinema's commercial motivations and technological origins, concerned about Hollywood's appeals to violence and eroticism, and insistent that cinema had not yet produced works of lasting value. Seldes, on the other hand, argued that cinema's popularity demanded that we reassess its aesthetic qualities.

Cinema and other popular arts were to be celebrated, Seldes said, because they were so deeply imbedded in everyday life, because they were democratic arts embraced by average citizens. Through streamlined styling and syncopated rhythms, they captured the vitality of contemporary urban experience. They took the very machinery of the industrial age, which many felt dehumanizing, and found within it the resources for expressing individual visions, for reasserting basic human needs, desires and fantasies. And these new forms were still open to experimentation and discovery. They were, in Seldes' words, "lively arts."

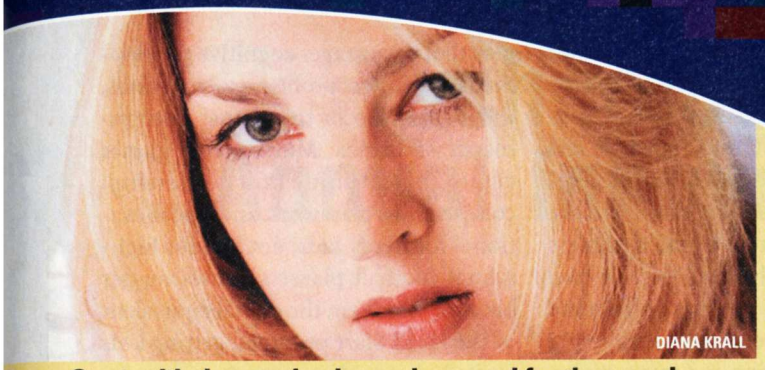
Games represent a new lively art, one as appropriate for the digital age as those earlier media were for the machine age. They open up new aesthetic experiences and transform the computer screen into a realm of experimentation and innovation that is broadly accessible. And games have been embraced by a public that has otherwise been unimpressed by much of what passes for digital art. Much as the salon arts of the 1920s seemed sterile alongside the vitality and inventiveness of popular culture, contemporary efforts to create interactive narrative through modernist hypertext or avant-garde installation art seem lifeless and pretentious alongside the creativity that game designers bring to their craft.

Much of what Seldes told us about the silent cinema seems remarkably apt for thinking about games. Silent cinema, he argued, was an art of expressive movement. He valued the speed and dynamism of D.W. Griffith's last-minute races to the rescue, the physical grace of Chaplin's pratfalls and the ingenuity of Buster Keaton's engineering feats. Games also depend upon an art of expressive movement, with characters defined through their distinctive ways of propelling themselves through space, and successful products structured around a succession of spectacular stunts and predicaments. Will future generations look back on Lara Croft doing battle with a pack of snarling wolves as the 21st-century equivalent of Lillian Gish making her way across the ice floes in *Way Down East*? The art of silent cinema was also an art of atmospheric design. To watch a silent masterpiece like Fritz Lang's *Metropolis* is to be drawn into a world where meaning is carried by the placement of shadows, the movement of machinery and the organization of space. If anything, game designers have pushed beyond cinema in terms of developing expressive and fantastic environments that convey a powerful sense of mood, provoke our curiosity and amusement, and motivate us to explore.

Seldes wrote at a moment when cinema was maturing as an expressive medium and filmmakers were striving to enhance the emotional experience of going to the movies—making a move from mere spectacle towards character and consequence. It remains to be seen whether games can make a similar transition. Contemporary games can pump us full of adrenaline, they can make us laugh, but they have not yet provoked us to tears. And many have argued that, since games don't have characters of human complexity or stories that stress the consequences of our actions, they cannot achieve the status of true art. Here, we must be careful not to confuse the current transitional state of an emerging medium with its full potential. As I visit game companies, I see some of the industry's best minds struggling with this question and see strong evidence that the games released over the next few years will bring us closer and closer to the quality of characterization we have come to expect from other forms of popular narrative.

In the March 6 issue of *Newsweek,* senior editor Jack Kroll argued that audiences will probably never be able to care as deeply about pixels on the computer screen as they care about characters in films: "Moviemakers don't have to simulate human beings; they are right there, to be recorded and orchestrated.... The top-heavy titillation of Tomb Raider's Lara Croft falls flat next to the face of Sharon Stone.... Any player who's moved to tumescence by digibimbo Lara is in big trouble." Yet countless viewers cry when Bambi's mother dies, and World War II

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veterans can tell you they felt real lust for *Esquire*'s Vargas girls. We have learned to care as much about creatures of pigment as we care about images of real people. Why should pixels be different?

In the end, games may not take the same path as cinema. Game designers will almost certainly develop their own aesthetic principles as they confront the challenge of balancing our competing desires for storytelling and interactivity. It remains to be seen whether games can provide players the freedom they want and still provide an emotionally satisfying and thematically meaningful shape to the experience. Some of the best games—Tetris comes to mind—have nothing to do with storytelling. For all we know, the future art of games may look more like architecture or dance than cinema.

Such questions warrant close and passionate engagement not only within the game industry or academia, but also by the press and around the dinner table. Even Kroll's grumpy dismissal of games has sparked heated discussion and forced designers to refine their own grasp of the medium's distinctive features. Imagine what a more robust form of criticism could contribute. We need critics who know games the way Pauline Kael knew movies and who write about them with an equal degree of wit and wisdom.

When *The Seven Lively Arts* was published, silent cinema was still an experimental form, each work stretching the medium in new directions. Early film critics played vital functions in documenting innovations and speculating about their potential. Computer games are in a similar phase. We have not had time to codify what experienced game designers know, and we have certainly not yet established a canon of great works that might serve as exemplars. There have been real creative accomplishments in games, but we haven't really sorted out what they are and why they matter.

But games *do* matter, because they spark the imaginations of our children, taking them on epic quests to strange new worlds. Games matter because our children no longer have access to real-world play spaces at a time when we've paved over the vacant lots to make room for more condos and the streets make parents nervous. If children are going to have opportunities for exploratory play, play that encourages cognitive development and fosters problem-solving skills, they will do so in the virtual environments of games. Multi-player games create opportunities for leadership, competition, teamwork and collaboration—for nerdy kids, not just for high-school football players. Games matter because they form the digital equivalent of the Head Start program, getting kids excited about what computers can do.

The problem with most contemporary games isn't that they are violent but that they are banal, formulaic and predictable. Thoughtful criticism can marshal support for innovation and experimentation in the industry, much as good film criticism helps focus attention on neglected independent films. Thoughtful criticism could even contribute to our debates about game violence. So far, the censors and culture warriors have gotten more or less a free ride because we almost take for granted that games are culturally worthless. We should instead look at games as an emerging art form—one that does not simply simulate violence but increasingly offers new ways to understand violence—and talk about how to strike a balance between this form of expression and social responsibility. Moreover, game criticism may provide a means of holding the game industry more accountable for its choices. In the wake of the Columbine shootings, game designers are struggling with their ethical responsibilities as never before, searching for ways of appealing to empowerment fantasies that don't require exploding heads and gushing organs. A serious public discussion of this medium might constructively influence these debates, helping identify and evaluate alternatives as they emerge.

As the art of games matures, progress will be driven by the most creative and forward-thinking minds in the industry, those who know that games can be more than they have been, those who recognize the potential of reaching a broader public, of having a greater cultural impact, of generating more diverse and ethically responsible content and of creating richer and more emotionally engaging stories. But without the support of an informed public and the perspective of thoughtful critics, game developers may never realize that potential. TR

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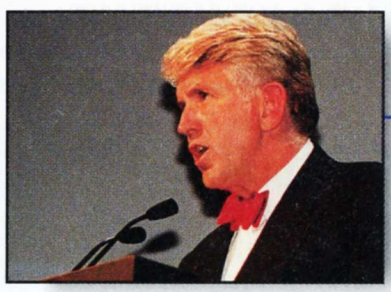
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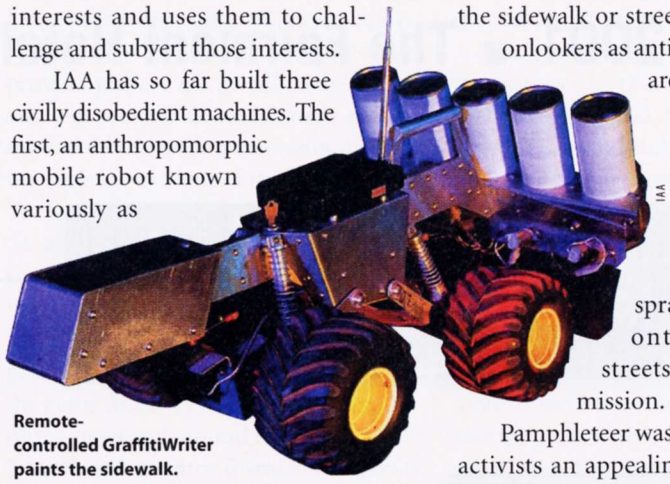
Roboprotest

Artists and engineers make subversive allies

WITH BODY-ARMORED RIOT POLICE poised like Teenage Mutant Ninja Turtles in front of a corporate city called Niketown, the uprising late last year against the World Trade Organization meeting in Seattle seemed science-fictional at times. If the Institute for Applied Autonomy (IAA) has its way, the future of civil disobedience will be even stranger. This team of artists has already engineered a new form of resistance: robot protesters.

Three disruptive automatons have now been manufactured by the IAA, an anonymous group of artists founded in 1998. The group's Web site (www.appliedautonomy.com) declares that it develops technologies for the "emerging market of cultural insurrection." While other researchers fashion robots to work in environments that are physically hazardous to humans, the IAA is building robots to speak out in areas where free speech has been regulated out of existence. The IAA takes technologies that have been developed to serve corporate, institutional and military interests and uses them to challenge and subvert those interests.

IAA has so far built three civilly disobedient machines. The first, an anthropomorphic mobile robot known variously as Pamphleteer, Little Brother or Petit Frère, proffers subversive literature to passersby. Its partner in protest, GraffitiWriter, functions much like a remote-control dot-matrix printer—one that uses an array of spray paint cans as its print head and the sidewalk as its blank page. GraffitiWriter has now been used more than 200 times in seven cities by, among others, a Girl Scout troop, a homeless man and a policeman. A larger-scale version of this robot, called StreetWriter, is now in the final stages of development. Mounted to a car bumper, it paints huge messages on the street in letters that are legible from tall buildings and low-flying aircraft. Though painting the sidewalk or streets may strike some onlookers as anti-social, these robots are in some sense only imitating certain forms of corporate activity: Reebok recently commissioned a New York City artist to spray-paint advertising onto sidewalks and streets without city permission.



Remote-controlled GraffitiWriter paints the sidewalk. A car-mounted version marks the street.

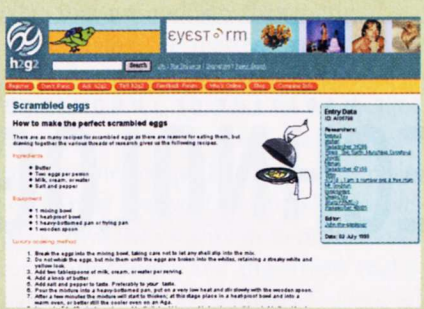
Pamphleteer was constructed to give activists an appealing metal face. IAA's Web site declares that the robot is intended to "bypass the social conditioning that inhibits activists' ability to distribute propaganda by capitalizing on the aesthetics of cuteness." The designers even gave the robot a childlike voice. A tongue-in-cheek research paper by the IAA documents how Pamphleteer

WEB SITE

An Earthly Prequel to a Galactic Guide

Douglas Adams' sci-fi satire *The Hitchhiker's Guide to the Galaxy* and its four sequels chronicle the interstellar exploits of a hapless human who is helped along on his journey by the novel's namesake—an ingenious handheld gadget that offers advice about almost any place, object, entity or event in the cosmos. The electronic handheld Guide, regularly updated by its users, is a forerunner of today's emerging e-books and wireless Internet access rolled into one.

Once totally fictional, Adams' concoction has led to the quite factual Earth Edition of the Hitchhiker's Guide to the Galaxy on the Web (www.h2g2.com). Launched in May 1999 by the London-based new media firm h2g2 Ltd. (formerly The Digital Village), it has grown into a community of more than 30,000 registered participants in 85 countries. These "researchers"—including Adams himself—post entries on all aspects of living on the planet, ranging from the quirky to the truly useful. Topics include alcoholic drinks, the world's best beaches, English, American and Australian slang, and the question of whether intelligent life exists on Earth. For fans of Adams' writing, among the most noteworthy finds are his wry entries on "Festive Hangover Cures" and "International Driving Laws."



Like the device in the books, h2g2 is a work in progress. As Adams recently wrote on the site: "The Guide itself, big as it has become, is still a little like the fossil record in that it consists almost entirely of gaps." Yet the power of h2g2 is that gaps can be filled, not only by researchers posting at will but also with responses to specific queries. Adams' request for information on scrambled eggs, for example, elicited entries on "How to make the perfect scrambled eggs" and the best places on Earth to eat scrambled eggs. Available since last December, a wireless version of h2g2 beamed to handheld devices and cell phones is the first step toward the real-time portable guide to the galaxy of Adams' imagination.

—Steve Ditlea

outperformed a human activist, distributing more literature as it worked uninterrupted for longer periods of time. The John Henry-style trial was conducted on street corners, but the IAA says Pamphleteer is now ready for deployment in malls, government buildings and business offices—places that ordinarily prohibit humans from distributing pamphlets. The IAA wants to use this robot's technological allure to critique the institutions that usually sell themselves with the same high-tech glitz.

The IAA is sticking its neck out when it deploys its protesting robots, since their actions leave their expensive electronics at risk of seizure. For some protesters, such as those who smashed Seattle storefronts and claimed that their destruction of property was nonviolent, deployment of robotic allies that are subject to similar smashing appears to complicate their position.

Other contexts invite additional complications. For instance, Pamphleteer would be a strange sight handing out fliers at picket lines where human workers are protesting increasing automation. Moreover, a technology that distances human protesters from the repercussions of illegally marking up the public pavement has some troublesome implications. Many means of civil disobedience have emphasized personal responsibility for one's reasonable but illegal actions; the IAA robots work against this trend.

The IAA robots do, however, represent an attempt to reclaim public space and open up new means of communication. They also raise interesting questions about the use of technology for control and disruption and point out how the appeal of new technologies can allow people to act without responsibility. Both the protested and the protesters should come away with new perspectives after a hands-on experience with the IAA's technologies of resistance.

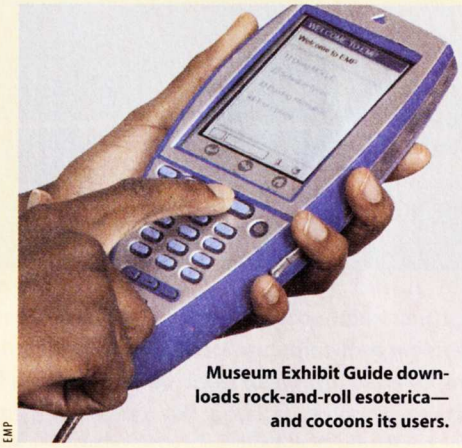
Gutenberg's printing press powered the Protestant Reformation and the American Revolution. Fax machines helped topple the Berlin Wall, and e-mail is undermining dictatorships around the world. Robots are thus stepping into a grand tradition of applying cutting-edge technology to foster political dissent. **—Nick Montfort**

EXHIBIT

Can Tech Learn to Rock?

Imagine if Microsoft crossed the Smithsonian Institution with the Hard Rock Cafe, then injected some genetic material from Cleveland's Rock and Roll Hall of Fame and Sony's multimedia Metreon entertainment center in San Francisco. The result might look something like the heavily hyped Experience Music Project (EMP), which opened early this summer at the foot of Seattle's famed Space Needle. Bankrolled to the tune of $250 million by Microsoft co-founder Paul Allen, the EMP began as an homage to Seattle native Jimi Hendrix. It has evolved into something much more—and somehow a bit less.

Housed in a spectacular Frank Gehry-designed building resembling a pile of giant melted gumdrops, the EMP puts a unique high-tech spin on American popular music. The facility—bisected by a monorail left over from a World's Fair—combines a traditional museum, high-tech entertainment proving ground and a new-age shopping mall and melds them into a kind of theme park for boomers. In addition to the Hendrix shrine and other traditional museum-style collections of rock and roll memorabilia, it boasts a number of high-tech innovations. A motion-simulator ride, for example, seems to dive through a trumpet and drop you into high-energy funk concerts by James Brown and Parliament-Funkadelic.



EMP

Museum Exhibit Guide downloads rock-and-roll esoterica—and cocoons its users.

The EMP seems even prouder of its interactive Sound Lab, where visitors can try their hand at creating their own music—with or without electronic assistance. You can step up to a specially modified electric guitar, for example, and follow the lights built into the frets to play along with The Kingsmen on "Louie, Louie" or Nirvana on "Smells Like Teen Spirit." If you miss the notes, the computer-controlled instrument offers more practice. Electronic drums use velocity sensors to control the size of the graphics on a display. A concert simulator synchs MIDI samples to a lyric generator to make you the star.

EMP's other major innovation is its ingenious Museum Exhibit Guide (MEG)—sort of a menage a trois involving a Sony Discman, a Palm Pilot and a TV remote control. One of these gizmos, which were custom-designed by Allen's firm Vulcan Northwest and rumored to cost $2,000 each, gets strapped to every EMP visitor right after they fork over the museum's $20 admission fee. You point the infrared remote unit at specially marked exhibits and it downloads relevant text and audio for immediate playback, bookmarking your selections for later retrieval in the EMP's computer lab or Web site (www.emplive.com). Choice bits range from blues stylings that led to the birth of rock and roll to singer David Johansen of the New York Dolls explaining why his group was so influential, even though nobody liked them much during their 1970s heyday.

If the technology is unquestionably cutting edge, sometimes it can seem more important than its subject. The concert simulator, for example, seems to run out of ideas on where to go once you actually reach the show; it energetically but awkwardly slings visitors around from soloist to soloist. MEG is a bit clumsy to use, and wearing the headphones isolates each visitor in a little cocoon of privacy.

That's the trouble with trying to mold technology into the service of something as visceral as rock and roll. No matter how slick its innovations, the EMP won't be as exciting as its subject until they figure out how to make the technology rock as hard as the music. Heck, it might help if they just turned up the volume a little. **— Fredric Paul**



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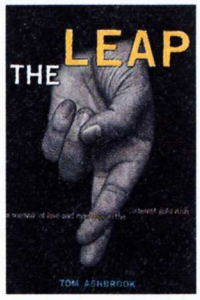
PAGES | BY WADE ROUSH

Life on the e-Frontier

THE LEAP: A MEMOIR OF LOVE AND MADNESS IN THE INTERNET GOLD RUSH

By Tom Ashbrook

Houghton Mifflin, 295 pp., $25



SCENE 1: TOM ASHBROOK, a *Boston Globe* foreign correspondent, and his former college roommate Rolly Rouse are running through the woods of Newton, Mass., "laughing like idiots and whooping and slapping trees." They're so high on their plan to become Internet entrepreneurs that Tom is "hopping up on a big rock, pissing a long arc into the woods, laughing and crowing like a goofy rooster."

Scene 2, two years later: Rolly has left the office with chest pain and numbness in his left arm. Tom, whose wife will shortly send him e-mail saying that she has been vomiting in the bathroom with stress over their dire financial picture, is banging away on his computer in a daze. "A little light was finally coming on somewhere deep in my mind," Tom later writes. "[Rolly] could be dead. He could have broken himself over this dream."

Scene 3, another year later: A venture capital firm has just called to commit $3 million to HomePortfolio.com, as the outfit is now called. Rolly and Tom are once again "roaring with joy. Riffing our air guitars. Leaping."

The Leap is Ashbrook's frank, intimate, funny memoir of the hair-raising process of starting, with Rouse, HomePortfolio.com, an Internet business that helps people design their homes and pick out the products they'll need. Without quite knowing why, but feeling he had no choice, Ashbrook left his successful career at the *Globe* for a life of infrequent paychecks, maxed-out credit cards and endless dog-and-pony shows before skeptical investors. Today, HomePortfolio.com has raised more than $25 million and is the leading site on the Web for previewing and buying premium home design products, like those $3,000 gold-plated faucets you always wanted for the guest bathroom. But if Ashbrook's colleagues had known what he and his family were about to go through when he resigned from the paper in 1996 to co-found the company, fewer of them might have expressed their envy.

This is the face of innovation in the new economy: the elation of having a new idea, the agony of pleading for money to get the idea off the ground, and, for a lucky few, the blessing of venture capitalists. There's little in Ashbrook's account to suggest that he was deeply passionate about home design or the company's business model. Instead, he seems driven by the raw need to be on the frontier, to build something out of nothing, the way his ancestors did when they took the leap and came to America. That takes courage, faith and a little bit of madness—all familiar strains in the history of innovation. Maybe this new economy isn't so new after all.

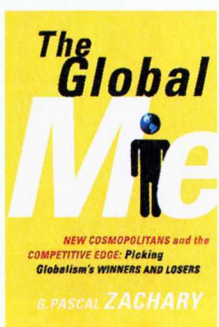
Mongrels 'R' Us

THE GLOBAL ME: NEW COSMOPOLITANS AND THE COMPETITIVE EDGE: PICKING GLOBALISM'S WINNERS AND LOSERS

By G. Pascal Zachary

PublicAffairs, 336 pp., $26

A RELATIVELY RECENT SCHOOL OF economic thought attributes to ethnically homogeneous nations such as Japan a social harmony and unity of purpose that virtually guarantees them an advantage over more diverse, less disciplined competitors. And in the late 1980s and early 1990s, as Japan's economy seemed ready to trounce that of the United States and racial divisions burned out of control in the streets of Los Angeles, many Americans were ready to agree. Nonsense, says author—and *TR* columnist—G. Pascal Zachary.



The Global Me is a passionate diatribe for "hybridity," Zachary's word for the mixing of racial and ethnic backgrounds within individuals and nations. "Under the right conditions, hybrid societies trump monocultures," he asserts. When conditions aren't right—when governments ignore racial discrimination and inequalities of wealth, or when immigrants are tolerated only as long as they take jobs that no native wants—hybridity can be a net drag. But when corporations go out of their way to hire foreign-born executives, or when children of interracial marriages are encouraged to bring both parents' cultures into their schools and workplaces, the result is greater innovation. One need only look at Silicon Valley—where one-third of the scientists and engineers are immigrants, and Chinese and Indian immigrants alone have founded 2,700 companies employing 58,000 people—to understand the power of hybridity.

Refreshingly, Zachary builds his argument not on dry economic statistics but on anecdotes and mini-biographies. Some of the most delightful parts of the book are the profiles preceding each chapter, about people like Radha Basu, an Indian-born manager of software development teams at Hewlett-Packard. One day Basu is coaching her German subordinates to be less secretive about their progress; the next, she is helping to smooth out misunderstandings between company engineers in Asia and company attorneys in America. "I feel like a global person," Basu says. "I feel I belong anywhere." Yet she hasn't forgotten her origins; indeed, they are the essence of her power. In a nice metaphor, Zachary says people like Basu have both "roots and wings."

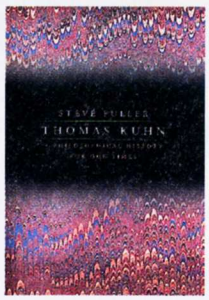
That said, *The Global Me* is also a very long book that takes a fairly simple argument and hammers it home relentlessly. Zachary is a *Wall Street Journal* reporter who seems a bit giddy over the relative freedom of book writing, often lapsing into the kind of hyper-serious,

pseudo-poetic prose where every sentence is its own paragraph. I wonder whether anyone who is not already a convert to Zachary's hybridity argument will have patience for it. If not, he at least offers a zippy and probably irrefutable take-home message: "Mongrelize or die!"

Dwarf Standing on Giants

THOMAS KUHN: A PHILOSOPHICAL HISTORY FOR OUR TIMES
By Steve Fuller
University of Chicago Press, 472 pp., $35

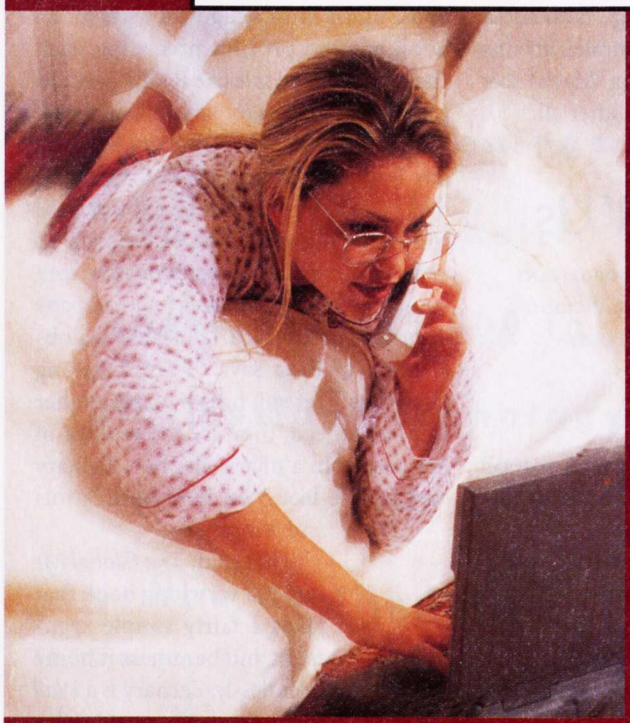
IF HISTORIANS OF SCIENCE HAD TO choose one book to represent their field to the world, it would not be Thomas Kuhn's *The Structure of Scientific Revolutions*. Yet this is the one history-of-science book that almost everybody, from Al Gore to Bob Metcalfe, knows about, the one that is constantly invoked for its beguilingly useful concept of paradigm shifts. In Kuhn's picture of science, investigators keep busy most of the time filling in the corners of the paradigm, or frame of reference, in which they were all trained. But over time, as anomalies that cannot be explained within the ruling paradigm accumulate, a new paradigm, or "revolution," emerges, after which everyone wonders why they ever thought differently. The problem with Kuhn's thesis is that he only meant it to describe one science, physics, and only during the period from 1620 to 1920—certainly not the 20th century's era of Big Science. Yet since the publication of *Structure* in 1962, the concept of paradigms and revolutions has been appropriated and (mis)applied in fields from biology to social science to business, to the enormous frustration of today's historians of science.



Books like Steve Fuller's *Thomas Kuhn: A Philosophical History for Our Times* are one product of this frustration. Fuller, a sociologist at the University of Warwick in Coventry, England, is deeply disappointed by what he calls the "acritical" stance Kuhn's work has fostered in the academy. He calls Kuhn a dwarf who stood on the shoulders of giants and attributes *Structure*'s ascendancy to a "comedy of errors" reminiscent of the Peter Sellers movie *Being There*.

Fuller's first line of attack is to show how rooted Kuhn's thesis was in its Cold War environs. Fuller chronicles Kuhn's early career at Harvard, where he came under the wing of university President James Bryant Conant, a true Cold Warrior and the era's leading advocate for Big Science. Conant's worldview left little room for public criticism of science, and according to Fuller this was played out in Kuhn's teaching and writing, which characterized scientific revolutions as the working-out of purely internal contradictions, free of any social, political or technological influ-

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ences. Post-*Structure*, Fuller charges, science and technology studies (STS) has put too much emphasis on case studies of the development of narrow scientific disciplines, rarely stepping back to examine the ends and means of science in general.

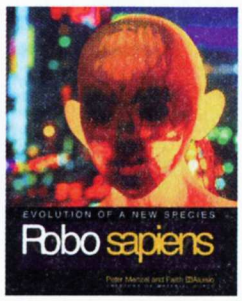
Fuller's arguments are persuasive and well-documented, and I share his view of STS. However, I have a harder time pinning the blame solely on Kuhn's book. If *Structure* has assimilated science studies, surely this has something to do with the lack of effective resistance.

Robot Dreams

ROBO SAPIENS: EVOLUTION OF A NEW SPECIES
By Peter Menzel and Faith D'Aluisio
MIT Press, 240 pp., $29.95

THE DELIGHTS OF *ROBO SAPIENS* START with its clever title, which could refer to either the "new species" of synthetic beings emerging from today's laboratories or the existing species that is so obsessed with building them. I prefer the latter, for while this is a book chock full of arresting images and information about the current state of robotics, it teaches you even more about the dreams and illusions of the roboticists.

There has always been a magical quality to machines that take on human form. The entertainment business has been banking on this popular fascination for decades, from the humanoid robot Maria in Fritz Lang's 1927 film *Metropolis* to her descendant C3PO. But photographer Peter Menzel and writer Faith D'Aluisio show that many roboticists have bought into this vision, spending millions to make their robots look or move more like humans even when this introduces unnecessary complexity or has no near-term payoff. Honda's P3 robot, for example, has arms and legs that bend like a human's and sophisticated software to monitor and adjust its center of gravity, giving it the ability to walk, open a door and descend a staircase. But even P3's creators admit they can't envision many uses for it beyond carrying heavy bags when its master goes shopping.



Other robots featured in the book aren't so anthropomorphic. There's a fascinating chapter on robots that move like other organisms such as roaches, snakes and lizards. But even here, as one of D'Aluisio's interviewees puts it, roboticists are "very focused on their robot behaving the same way as the animal." This is fine if you are primarily interested in deconstructing animal behavior, but how will it lead to designs that meet specific human needs? As I read, I gained sympathy for the underfunded builders of truly useful robots such as Nomad, a four-wheeler that's roaming Antarctica looking for ancient meteorites. Now and for a long time to come, our most effective robots may look nothing like us. TR

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COURTESY OF RICHARD SMALLEY; COLOR ENHANCEMENT: DAVID PELOSI

Scissors, Paper...Buckyballs

A soccer-ball-shaped molecule kicked off a nanotech revolution

A PAIR OF SCISSORS, A LEGAL PAD, A LATE NIGHT BEER. All ordinary items, but together they helped an extraordinary tool—nanotechnology—take its first steps out of the realm of theory and into practice.

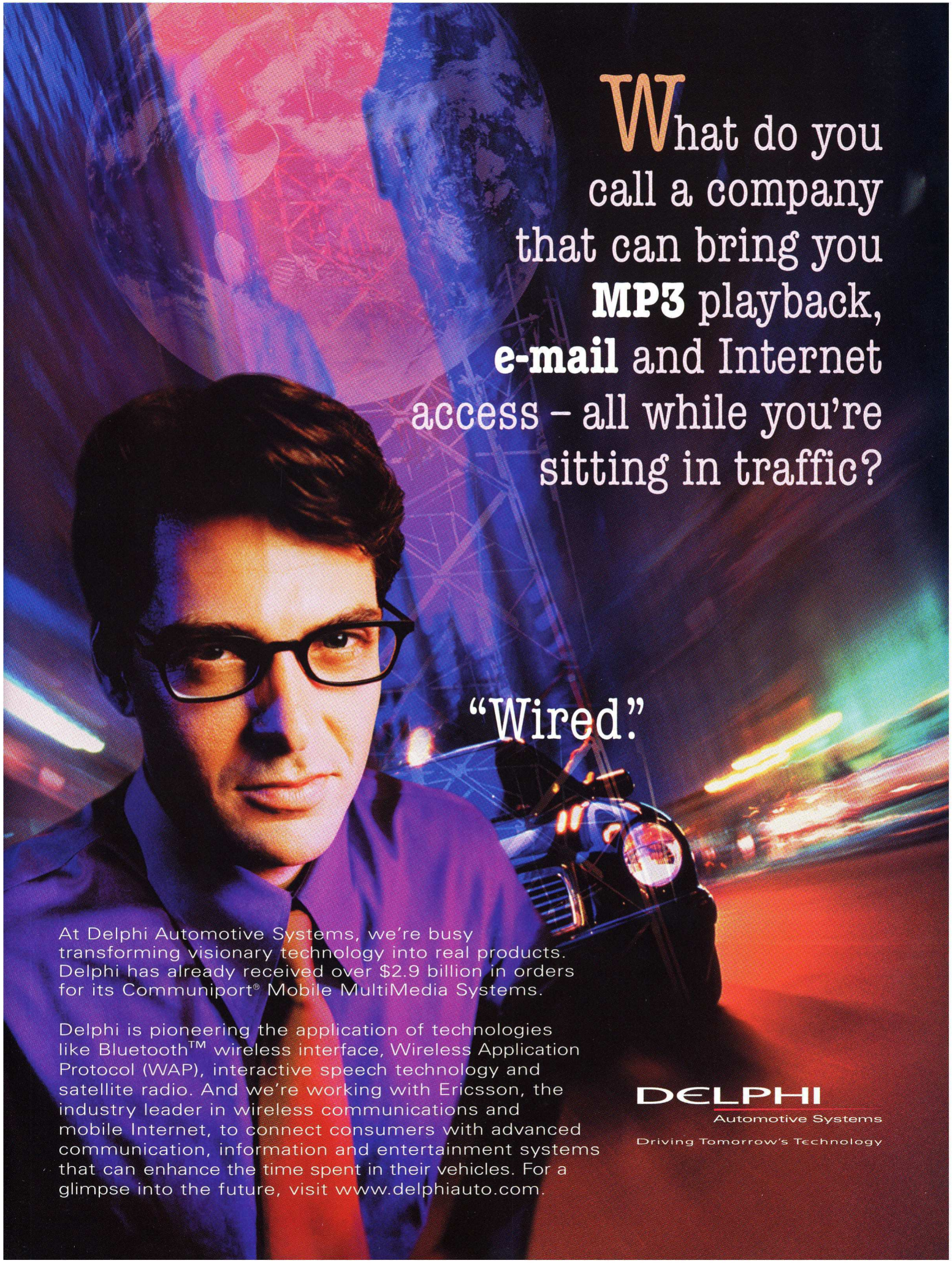
It started with stardust. In 1985, University of Sussex astronomer Harry Kroto teamed up with Rice University chemists Richard Smalley and Robert Curl to study the structure of carbon molecules on the surface of red giant stars. Along with graduate students James Heath and Sean O'Brien, they mimicked star conditions by zapping carbon with lasers and found something unexpected: a high proportion of extremely stable clusters with 60 carbon atoms each. Someone in the group—nobody remembers who—suggested each cluster might be a single molecule shaped like a hollow ball.

The team struggled to build a model, something like two fused geodesic domes. Smalley worked first on a computer but got nowhere. Heath tried making the shape with gumdrops and toothpicks but failed. Smalley resorted to cutting out hexagons from a legal pad, trying to assemble a sphere from them. Still no luck. But after a post-midnight beer, he remembered geodesic domes can contain pentagons as well as hexagons. Finally, success. Twenty hexagons and 12 pentagons made a 60-atom sphere—a carbon soccer ball. The team dubbed it "buckminsterfullerene," after the polymath architect who created the geodesic dome.

On September 11, a day before they submitted their findings to the journal *Nature,* O'Brien, Smalley, Curl, Kroto and Heath (left to right, above) posed for a photo with a pair of "buckyball" models and a soccer ball. When the paper ran in November, chemists, physicists and materials scientists were intrigued by the newly discovered form of carbon. The field got another big boost in 1991 when NEC researcher Sumio Iijima discovered an important chemical cousin—the first nanotube. Researchers have used these buckytubes to create tiny experimental diodes, metal-filled "nanowires" and even a flat-screen display with a picture as sharp as conventional television's. The discovery that kicked it all off won Smalley, Curl and Kroto a 1996 Nobel Prize and opened the door to advances in fields ranging from medicine to computing, batteries to building materials. ◊

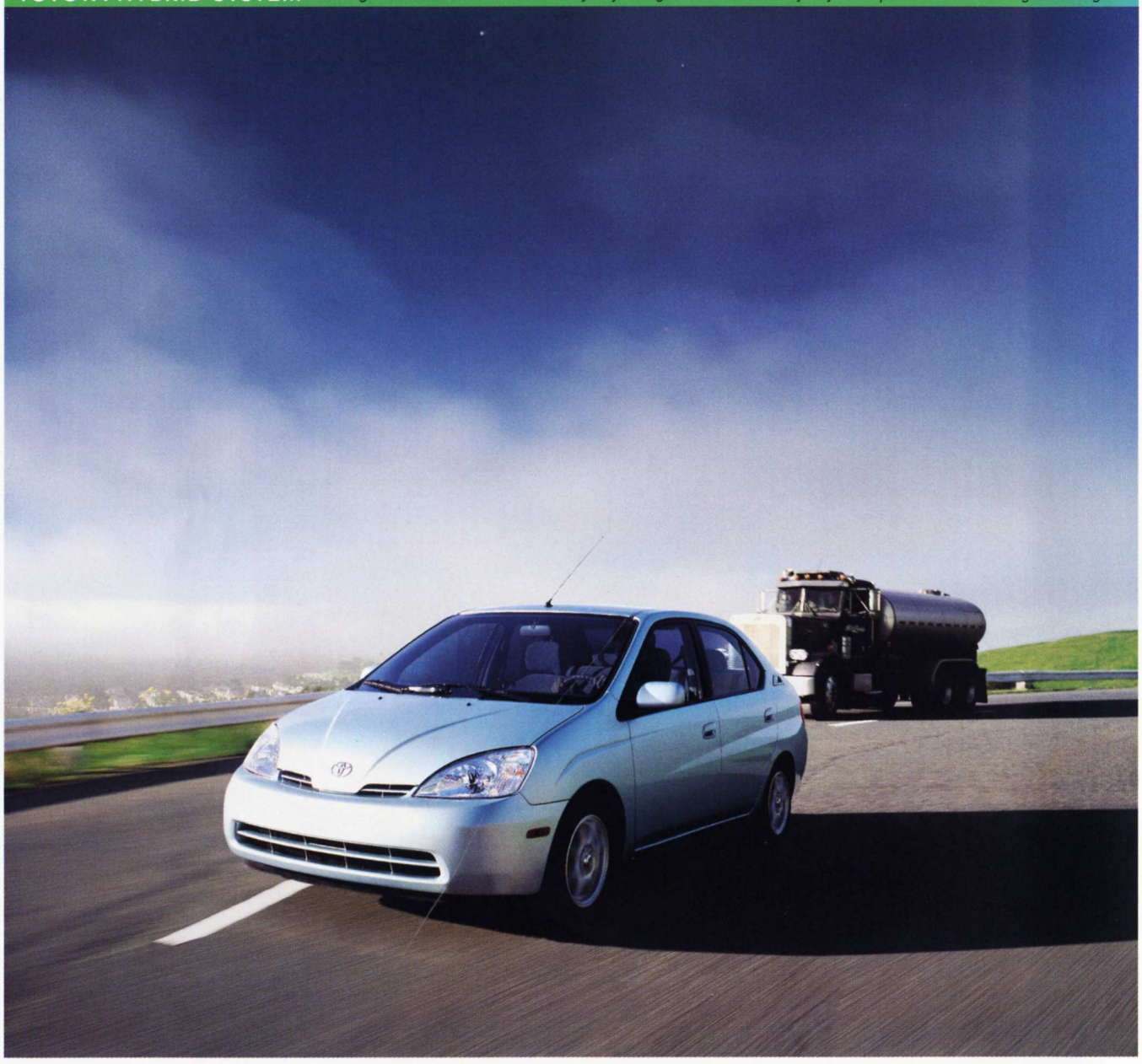
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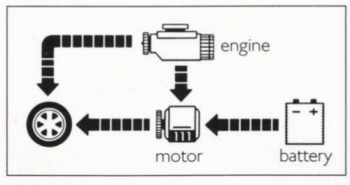
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